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Task Order 0027: Lighter Than Air (LTA) and Hybrid Aircraft Concept Assessment Tool Development

Blaine Rawdon, Zachary Hoisington, and Kevin Sequeira

The Boeing Company

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Final Report

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This report accompanies a new airship advanced design tool called “Advanced Airship Analysis and Design.” This report describes the tool’s features, explores sizing and performance results for several airship configurations for several missions and outlines the influence of advanced technologies on these results. The tool may be used to evaluate existing or proposed airship designs. It may also be used to create new designs. The tool includes integrated modules for aerodynamics, stability and control, structures and weight, propulsion. These are brought together in a module for sizing and performance estimation. The tool is executed in Microsoft Excel. A detailed user manual accompanies the tool and this report.

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TABLE OF CONTENTS

Section	Page
List of Figures	vi
List of Tables	viii
Preface	ix
Acknowledgements by the Principal Investigator	x
1 Summary	1
2 Introduction	2
3 Methods, Assumptions and Procedures	3
3.1 Inputs, Outputs, and Limitations	3
3.1.1 A3D Inputs	3
3.1.2 A3D Outputs	3
3.1.3 Limitations	3
3.2 A3D Architecture	3
3.2.1 Performance	4
3.2.2 Geometry 1	5
3.2.3 Geometry 2	8
3.2.4 Layout	10
3.2.5 Stability and Control	10
3.2.6 Main Weights	11
3.2.7 Section Weights	11
3.2.8 Lifting Gas	12
3.2.9 Propulsion Tanks	12
3.2.10 Cargo Bay Weights	12
3.2.11 Air Cushion Landing System (ACLS) Weights	13
3.2.12 Aerodynamics	13
3.2.13 Biconvex CFD	13
3.2.14 Trilobe CFD	14
3.2.15 Aero Loads	15
3.2.16 Loading	15
3.2.17 Structures Definition	15
3.2.18 Propulsion	16
3.2.19 Mission and Wind 2	16
3.2.20 Buoyancy Compensation	17
3.2.21 Solar	17
3.2.22 Internal Combustion Engine	18
3.2.23 Survivability, Threat Detail and Countermeasures Detail	18
4 Results and Discussions	19
4.1 Concept Development	19
4.1.1 Tactical Transport Case	22
4.1.2 Strategic Transport Case	23
4.1.3 Persistent Stare Platform/Intelligence Surveillance, Reconnaissance (ISR) Case	24
4.2 Technology Assessment Results and Discussion	26
5 Conclusions	28
6 Recommendations	29

TABLE OF CONTENTS (CONTINUED)

Section **Page**

6.1 Potential Tool Improvements 29
6.1.1 Solar 29
6.1.2 Cargo Loading Alternatives 29
6.1.3 Improved Buoyancy Compensation 29
6.1.4 Wind 29
6.1.5 Loads and Structures 30
6.1.6 Aerodynamic Database Improvements 30
6.1.7 Additional Configurations 30
7 References 31
Appendix Software User Manual 32
A1 Introduction 33
A2 Tool Concept 34
A2.1 A3D Architecture 34
A3 General Notes 36
A3.1 Excel Concept 36
A3.1.1 Cells 36
A3.1.2 Pages 36
A3.1.3 Graphics 36
A3.1.4 Macros 37
A3.1.5 Hide and Unhide / Grouping Cells 37
A3.1.6 Preparations to Run 37
A3.1.7 Division into User Areas and Calculation Areas 38
A4 Performance 39
A4.1 Performance Concept 39
A4.1.1 Airship and Mission Selector 39
A4.1.2 Key Airship Results 40
A4.1.3 Airship Inputs 40
A4.1.4 Results Summary 41
A4.1.5 Airship Performance – Sizing Mission 43
A4.1.6 Airship Performance – Reference Mission. 43
A4.2 Airship Performance Inputs 44
A5 Vehicle Geometry 45
A5.1 Vehicle Geometry Concept 45
A5.1.1 Coordinate System 45
A5.1.2 View 45
A5.1.3 Symmetry 46
A5.1.4 Archive 46
A5.1.5 Concept of Vehicle Geometry Inputs 46
A5.2 Geometry on “Performance” Page 47
A5.3 Geometry on “Geometry 1” Page 47
A5.3.1 Geometry1 Concept 47
A5.3.2 Geometry1 Background 48
A5.3.3 Rho-Value Conic Curves 48

TABLE OF CONTENTS (CONTINUED)

Section **Page**

A5.3.4 Geometry1 Inputs 49
A5.4 Geometry on the "Geometry 2" Page 61
A5.4.1 Geometry2 Concept 61
A5.4.2 Geometry2 Inputs 61
A6 Geometry on "Layout" Page 66
A6.1 Layout Concept 66
A6.2 Engine Geometry 66
A6.2.1 Fin Geometry 67
A6.2.2 Gondola Geometry 68
A6.2.3 Discrete Masses 69
A6.2.4 Detailed Inputs 69
A7 Main Weights 71
A7.1 Weights Concept 71
A7.2 Weights Inputs 71
A7.3 Weights Outputs 71
A8 Section Weights 73
A9 Lifting Gas 75
A9.1 Lifting Gas Concept 75
A10 Propulsion Tanks 76
A10.1 Propulsion Tanks Concept 76
A10.2 Propulsion Tanks Inputs 76
A10.2.1 Tank Geometry 76
A10.2.2 Other Tank Inputs 76
A10.3 Propulsion Tanks Outputs 76
A11 Cargo Bay Weights 77
A11.1 Cargo Bay Weights Concept 77
A11.2 Cargo Bay Weights Inputs 77
A11.2.1 Strength and Loads 77
A11.2.2 Cargo Bay Dimensions 77
A11.2.3 Cargo Floor Characteristics 77
A11.2.4 Ramp Characteristics 78
A11.2.5 Installation Factors 78
A11.2.6 Areal Weights 78
A11.3 Cargo Bay Weights Calculations 79
A11.3.1 Floor 79
A11.3.2 Ramp 79
A11.3.3 Walls 80
A11.3.4 Ceiling 80
A11.3.5 Cargo Handling Systems 80
A11.3.6 Total Cargo Bay Weight 80
A12 Air Cushion Landing System (ACLS) Weights 81
A12.1 ACLS Concept 81
A12.2 ACLS Inputs 81

TABLE OF CONTENTS (CONTINUED)

Section **Page**

A12.3 ACLS Calculations ... 82
A13 Stability and Control ... 84
A13.1 Stability and Control Concept ... 84
A13.2 Stability and Control Inputs ... 84
A13.2.1 Ballonet Properties ... 84
A13.2.2 Envelope Aerodynamic Properties ... 84
A13.2.3 Fin Properties ... 85
A13.2.4 Propulsion Properties ... 85
A13.2.5 Excess Drag Properties ... 86
A13.2.6 Simulation Trim Parameters ... 86
A13.2.7 Simulation Data Recording ... 86
A13.2.8 Perturbation Simulation Properties ... 86
A13.3 Stability and Control Calculations ... 86
A13.3.1 Calculate Virtual Mass Properties ... 86
A13.3.2 Fin Size Analysis ... 87
A13.3.3 Trim the Aircraft ... 92
A13.3.4 Trim the Aircraft and Linearize ... 92
A13.3.5 Trim, Linearize, and Perform Bare Airframe Disturbance Simulations ... 92
A14 Structures Definition ... 94
A15 Aerodynamic Loads ... 95
A15.1 Loads Concept ... 95
A15.2 Loads Inputs ... 95
A15.3 Loads Calculations ... 95
A16 Loading ... 96
A17 Control ... 97
A18 Aerodynamics ... 98
A18.1 Aerodynamics Concept ... 98
A18.2Aerodynamics Inputs ... 98
A18.3 Aerodynamics Outputs and Calculations ... 98
A18.3.1 Fin and Pylon Drag ... 98
A18.3.2 Nacelle ... 98
A18.3.3 Gondola and Miscellaneous Components ... 99
A18.3.4 Envelope ... 99
A19 Bi-Convex CFD ... 100
A19.1 Bi-Convex CFD Concept ... 100
A19.2 Bi-Convex Inputs ... 100
A19.3 Bi-Convex Calculations ... 100
A20 Tri-Lobe CFD ... 102
A20.1 Tri-Lobe CFD Concept ... 102
A20.2 Tri-Lobe CFD Inputs ... 102
A20.3 Tri-Lobe CFD Calculations ... 102
A21 Mission ... 103
A21.1 Mission Concept ... 103

TABLE OF CONTENTS (CONCLUDED)

Section **Page**

A21.2 Mission Inputs ... 103
A22 Wind2 ... 104
A22.1 Wind2 Concept ... 104
A22.2 Wind2 Inputs ... 104
A22.3 Wind2 Calculations ... 104
A23 Buoyancy Compensation ... 105
A23.1 Buoyancy Compensation Concept ... 105
A23.2 Buoyancy Compensation Inputs ... 105
A23.3 Buoyancy Compensation Calculations and Outputs ... 106
A24 Solar ... 107
A24.1 Solar Concept ... 107
A24.2 Solar Inputs ... 107
A24.2.1 Solar Energy Model Parameters ... 107
A24.2.2 Solar Panel Parameters ... 108
A24.2.3 Array Size ... 108
A24.3 Solar Outputs ... 108
A25 Internal Combustion Engine ... 109
A25.1 Internal Combustion Engine Concept ... 109
A26 Survivability ... 110
A26.1 Survivability Concept ... 110
A26.2 Survivability Inputs ... 110
A26.2.1 Probability of Hit ... 110
A26.2.2 Probability of a Kill ... 111
A26.3 Survivability Calculations and Outputs ... 112
A27 Threat Detail ... 114
A27.1 Threat Detail Concept ... 114
A27.2 Threat Detail Inputs ... 114
A27.3 Threat Detail Calculations and Outputs ... 114
A28 Countermeasures Detail ... 115
A28.1 Countermeasures Concept ... 115
A28.2 Countermeasures Inputs ... 115
A28.3 Countermeasures Calculations and Outputs ... 115
List of Acromyms, Abbreviations, and Symbols ... 116

LIST OF FIGURES

Figure **Page**

Figure 1. Diagram of Basic A3D Architecture ... 4
Figure 2. Example Wireframe Display of the Active Airship (ZPG-3W) ... 5
Figure 3. Example Sizing and Reference Mission Profiles ... 5
Figure 4. Example Maximum Half-Breadth Definition (ZPG-3W) ... 6
Figure 5. Example Cross Section Definition (ZPG-3W) ... 6
Figure 6. Example Single-Lobe Cross Section Shapes ... 7
Figure 7. Example Envelope with Modified Cross Sections in the Mid-Section ... 7
Figure 8. VRML Render of the USS Macon ... 8
Figure 9. CATIA Render of Trilobe Envelope ... 8
Figure 10. Example Centerline Lateral Offset Plot for a Three-Lobe Airship ... 9
Figure 11. Example Four-Lobe Cross Section ... 9
Figure 12. Example Four-Lobe Envelope from the Cross Section Shown in Figure 11 ... 9
Figure 13. Example Airship with Propulsion, Fins and Labeled Discrete Masses ... 10
Figure 14. Plot of Running Moments versus Airship Length ... 12
Figure 15. Matrix of Biconvex Airship Envelope Forms ... 14
Figure 16. Matrix of Trilobe Airship Envelope Forms ... 14
Figure 17. Combined Aerodynamic and Inertial Loads Shown by Color ... 15
Figure 18. Global Map with Wind Velocity, Origin and Destination, and Route. ... 17
Figure 19. Axially-Symmetric Airships with Varying Length-to-Diameter Ratios ... 19
Figure 20. Biconvex Airships with Varying Length-to-Diameter Ratios ... 20
Figure 21. Trilobe Airships with Varying Length-to-Diameter Ratios ... 20
Figure 22. Envelope Volume versus L/D for Three Envelope Species ... 20
Figure 23. Fuel Weight versus L/D for Three Envelope Species ... 21
Figure 24. Estimated Cost versus L/D for Three Envelope Species ... 21
Figure 25. Axially-Symmetric Tactical Transport ... 22
Figure 26. Biconvex Tactical Transport – Option 1 ... 23
Figure 27. Biconvex Tactical Transport – Option 2 ... 23
Figure 28. Biconvex Strategic Transport ... 23
Figure 29. Axially-Symmetric ISR Airship for 20,000 ft Altitude ... 24
Figure 30. Axially-Symmetric ISR Airship for 60,000 ft Altitude ... 25
Figure 31. Fuel Weight versus Subsystem Weight Reduction ... 26
Figure 32. Envelope Volume versus Subsystem Weight Reduction ... 27
Figure 33. Flexible Skin Fixed Wing Airlifter ... 30
Figure A- 1. Diagram of Basic A3D Architecture ... 34
Figure A- 2. Airship and Mission Selector Buttons ... 39
Figure A- 3. Indication of Selected Airship ... 40
Figure A- 4. Example Isometric Illustration of the GZ-20A Airship ... 41
Figure A- 5. Sizing and Reference Mission Profile for GZ-20A Airship ... 42
Figure A- 6. Summary Mission Results and Converge Buttons ... 42
Figure A- 7. Hull Lift Coefficient versus Mission Distance for the GZ-20A Airship. ... 43
Figure A- 8. Standard and Custom View Buttons ... 45
Figure A- 9. Custom View Inputs ... 45
Figure A- 10. Example View Options: Isometric, Top, Side and Front ... 46

LIST OF FIGURES (CONCLUDED)

Figure **Page**

Figure A- 11. Example Rho-Value Conic Sections with Rho = 0.1, 0.5 and 0.9 48
Figure A- 12. Example Quarter Circle Formed by Rho-Value Conic 49
Figure A- 13. Top View MHB Outline... 49
Figure A- 14. Additional Top View MHB Outline... 51
Figure A- 15. Envelopes with Common Inputs but Different Length to Diameter Ratios.......... 52
Figure A- 16. Cross Sections with Upper Corner Point Y-Values of 1.00, 0.50 and 1.25. 53
Figure A- 17. Cross Sections with Lower Corner Point Y-Values of 0.50, 1.25 and 0.75.......... 53
Figure A- 18. Isometric of Envelope with Upper and Lower Corner Points Set at Y = 0.50...... 54
Figure A- 19. Effect of “Width Fraction of Height” Input. 54
Figure A- 20. Isometric of Envelope with Central Sections Width/Height Ratio Set to 0.50..... 55
Figure A- 21. Example Cross Sections with Raised and Lowered Midpoint Height 55
Figure A- 22. Envelope with Midpoint Height Lowered to -0.50 56
Figure A- 23. Top View Plot of MHB... 57
Figure A- 24. Cross Section View 57
Figure A- 25. Cross Section Inputs Plot 58
Figure A- 26. Three-Dimensional View of Bare Envelope 58
Figure A- 27. Three-Dimensional View of Envelope with Components 58
Figure A- 28. VRML Render of the USS Macon 60
Figure A- 29. CATIA Render of Tri-lobe Envelope... 60
Figure A- 30. Lobe Centerline Definition Plot 62
Figure A- 31. Three-Lobe Envelope... 63
Figure A- 32. Four-Lobe Envelope and Cross Section... 63
Figure A- 33. Example Showing Non-Zero Lobe Start and End Points..................................... 63
Figure A- 34. Example Effect of Vertical Lobe Centerline Variations 64
Figure A- 35. Example Plot of Radius versus Length 64
Figure A- 36. Contrasting Example of Radius versus Length... 64
Figure A- 37. Front View Showing Unusual Component Installation 67
Figure A- 38. Running Moments... 73
Figure A- 39. Magnified Running Moment of MTOGW with Lifting Gas................................ 74
Figure A- 40. Aft View of Airship Showing Control Surface Deflection Convention 85
Figure A- 41. Equivalent Vertical Tail Area and Average Fin Moment Arm............................ 88
Figure A- 42. Equivalent Horizontal Tail Area and Average Tail Moment Arm........................ 89
Figure A- 43. Estimated Turning Radius... 90
Figure A- 44. Vertical Fin Stability Criteria 91
Figure A- 45. Horizontal Fin Stability Criteria... 91
Figure A- 46. Bare Airframe Response to Longitudinal Speed Perturbation 93
Figure A- 47. Example Bi-Convex Form with 7.07 L/H and 3.53 L/W.................................. 100
Figure A- 48. Example Tri-Lobe Form with 4.30 L/H and 2.54 L/W. 102
Figure A- 49. Survivability Matrix Threat Classes.. 110
Figure A- 50. Survivability Probability of a Hit Example.. 111
Figure A- 51. Probability of Kill and Survival Output for Small Arms and Cannon Fire......... 113

LIST OF TABLES

Table **Page**
Table A- 1. Values Adjusted by Each Converge Button 41
Table A- 2. Control Point Inputs for Top View MHB Outline 50
Table A- 3. Control Points for Additional Top View MHB Outline 51
Table A- 4. Inputs for Lobe Centerline Definition 62
Table A- 5. User Supplied Aerodynamic Coefficients 84
Table A- 6. Trim Data 92
Table A- 7. Variable Name Descriptions 93

PREFACE

The Advanced Airship Analysis and Design (A3D) tool and documentation were created by the Boeing Research and Technology organization in Huntington Beach and Seal Beach, California. Kevin J. Sequeira was the Principal Investigator and was responsible for the mass properties related modules, helped to code the A3D tool, and provided airship technical expertise. Zachary C. Hoisington was the primary architect of the A3D tool, devising numerous methods to rapidly visualize concepts, converge multiple designs, and increase tool efficiency. Joshua M. Kusnitz was also a key architect of the tool, responsible for coordinating the aerodynamics and loads modules, and creating the solar module and CATIA models needed for Computational Fluid Dynamics (CFD) analysis. Blaine K. Rawdon wrote much of this technical report and the User Manual and provided airship technical assistance as needed. Bryan E. Kashawlic created the stability and control module. Pichuraman Sundaram created the CFD database used for the multilobe and biconvex aerodynamics modules. Robert E. Grip created the structures analysis modules. Gilles De Brouwer and Eric Boekeloo derived aero loads from the CFD runs for use in the structures modules. Aaron J. Kutzmann created the initial CATIA models and the method for transferring configurations from Excel wireframe to CATIA. Jamie Childress created the survivability module. Kevin Lutke is responsible for the contract proposal and for the name of the software (A3D). Johannes Eissing from Airship Ventures provided the cost module. Program oversight was provided by Brian L. Foist.

ACKNOWLEDGEMENTS BY THE PRINCIPAL INVESTIGATOR

On behalf of the Boeing team, the Principal Investigator would like to thank the Air Force Research Lab (AFRL) team, led by Trenton White, for providing the opportunity and trust to make this project a success over the last two years. The intent of this was always to bring to light what airships can and can't do with unbiased analysis so that what little airship funding there is can be directed to a fruitful end. In cooperation with the AFRL team, Boeing has developed the basis of a powerful tool which we hope will continue to be refined so that a solution for a viable modern and game-changing airship can be found. I would also like to extend sincere gratitude to the Boeing team and Airship Ventures consultant. Without their expertise and effort, none of this would have been possible. A special thanks to John Skorupa of Boeing who initially supported me as configurator for his hybrid thermal airship.

1 SUMMARY

An advanced airship analysis and design tool is created and described. This tool may be used to evaluate existing and proposed airships. It may also be used to design new airships. The tool requires relatively few inputs and provides approximate characteristics in little time. The tool is created in Microsoft Excel, permitting direct examination, simple modification, and diverse graphics.

The tool considers airship payload; aerodynamic lift and drag; buoyancy; stability and control; structural loads, materials and weight; mass properties including center of buoyancy and mass; and propulsion. The tool can be used to estimate the performance of a specified, fixed airship or can size an airship to provide specified performance.

Different envelope types can be evaluated. These include axially-symmetric, multilobe, and biconvex shapes. These can be formed with a wide range of proportions. Resulting aerodynamic characteristics are approximated from a database of computational fluid dynamics runs.

Performance is evaluated by running a multi-segment mission including climb, cruise, and descent. Sizing is accomplished with selected constraints on envelope size, propulsion, and range.

Delivery of this tool indicates that a new capability has been achieved by the Air Force. The Air Force previously had very little in terms of LTA and hybrid aircraft analysis capability. Although the fidelity of this tool is low and intended for conceptual design analysis, it vastly improves Air Force analysis capability. By expanding into a new configuration space, more air vehicle alternatives for cargo transport and ISR missions can be generated and analyzed. These alternative concepts can be passed on to higher-level mission effectiveness studies that can show the impact of an airship fleet on mission effectiveness metrics, such as time to close, fuel burned, time on station, and cost.

2 INTRODUCTION

This report describes work performed for the Air Force Research Laboratory under Contract FA8650-08-D-3857 – Task Order 0027. This effort provides a conceptual tool for airship design and a user manual for the tool, exercises the tool by creating several airships, and compiles attractive future airship technologies.

Documentation for this effort is divided into two major sections. The main report section describes the design tool, example airship designs, and future airship technologies. The tool's user manual is included as an appendix to this report.

The tool is named Advanced Airship Analysis and Design, or A3D for short. A3D is a Microsoft Excel spreadsheet arrayed on multiple pages and is augmented by numerous automated subroutines known as macros. Use of Excel eases development and later modification. Its equations and structure are entirely visible if not always immediately apparent.

A3D supports rapid conceptual design of a wide range of airships intended for many different missions. It accommodates alternative airship geometries including axially-symmetric, multilobe and biconvex envelope forms. Its methods address wide variations in size. Different aspects of the design process are addressed by different pages of the spreadsheet. These include geometry, loads, structure, mass properties, aerodynamic lift and drag, propulsion, wind and solar power.

A3D is useful at the conceptual level to identify promising configurations, missions, and technologies. It also performs conceptual-level sizing. A3D is not intended for the preliminary design of a specific airship – this requires a level of detail an order of magnitude greater than is appropriate for a conceptual design tool.

A3D is an airship design and evaluation tool. It can be used to create new airships from scratch to meet a specified mission. In this role, A3D can help to explore the effect of alternative technologies, configurations, and mission requirements on airship sizing or performance.

A3D can also be used to evaluate existing or proposed airship designs. Evaluation of existing airship designs with known performance can be used to validate or calibrate the tool. Technology or mission changes to the existing design can also be explored. Evaluation of proposed designs can confirm or refute other performance estimates for the designs.

3 METHODS, ASSUMPTIONS AND PROCEDURES

3.1 Inputs, Outputs, and Limitations

3.1.1 A3D Inputs

A3D inputs are described in some detail in the user manual. In general terms, inputs include:

- sizing mission requirements including payload, range, cruise and maximum speed, cruise and maximum altitude
- Reference mission requirements
- Geometry of the envelope, cargo compartment, propulsion system and fins
- Weights
- Propulsion system characteristics
- Configuration
- Atmospheric conditions (gust loads)
- Material properties
- Origin, destination and season (wind effects)
- Survivability characteristics.

3.1.2 A3D Outputs

Outputs are carefully described in the user manual. A3D may be operated in different ways according to desired constraints. For instance, when evaluating an existing design, geometry and weight can be constrained to estimate fuel burned. When designing a new airship, size and weight are unconstrained and are sized to provide specified mission performance. Key outputs include:

- Sized geometry including envelope length and volume
- Sized mass properties
- Sized tails
- Sized engine power
- Fuel burned.

3.1.3 Limitations

A3D has limitations in fidelity and capability. These are due in part to the balance needed in a conceptual design tool between ease of use and fidelity. They are also due to the finite duration and resources of the tool's development. Estimation of airship characteristics from a limited set of inputs is necessarily imprecise. Airship weight is probably the most uncertain characteristic due to the complexity of airship structural loads and analysis as well as a scarce historical database for novel designs. Drag and propulsion system characteristics are less uncertain.

3.2 A3D Architecture

A3D is built in Microsoft Excel. It is spread over some 29 interlinked pages. A single main page called "Performance" is the integrating hub of the tool. The other pages are dedicated to individual disciplines. These read data from the Performance page, perform computations and send results back to the Performance page. This architecture is represented graphically in Figure 1.

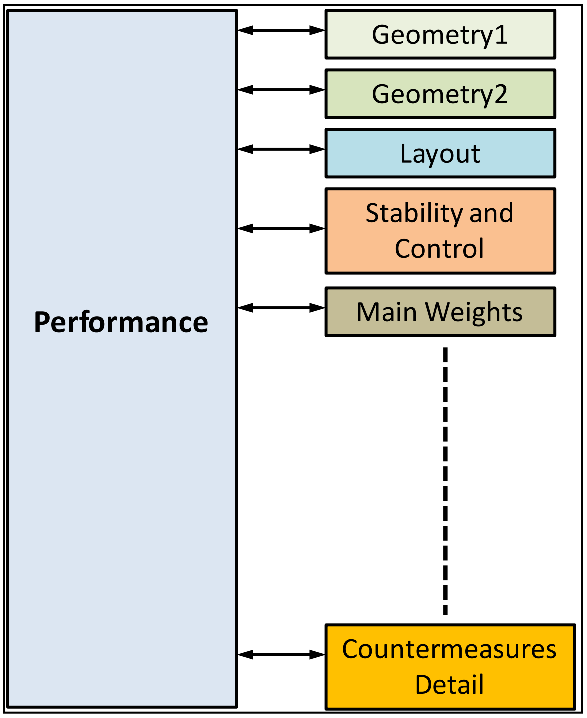


Figure 1. Diagram of Basic A3D Architecture

The following sections briefly describe each page of the tool. Each section heading is the name of the tool page.

3.2.1 Performance

The Performance page is the integrating hub of A3D. It is also the primary page from which the program is operated.

Key components of the Performance page are listed:

- Instrument panel. This section displays all key values for the active airship design. Key values include mission requirements, geometry, weights, propulsion, and configuration. This panel is always visible at the left side of the Performance page.
- Archive. This section stores the key values for 15 different airships in columns that align with the instrument panel to its left. Selection of the active design is made by toggling from one column to the next with left and right arrow buttons. A3D is delivered with 15 airships already loaded in the archive section.
- Wireframe display of the active airship. An example of this is shown in Figure 2. This view may be changed by clicking different view buttons such as isometric, front, etc.

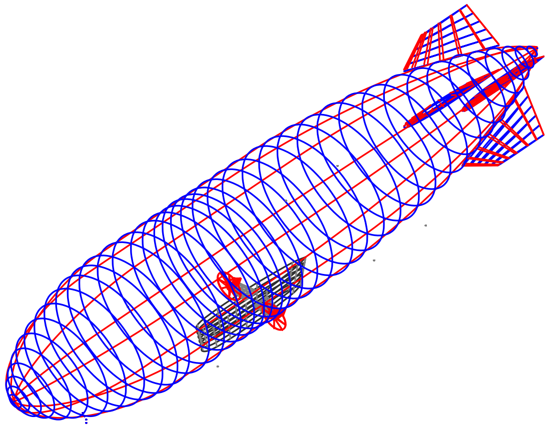


Figure 2. Example Wireframe Display of the Active Airship (ZPG-3W)

- Plot of mission profile. This plot shows the altitude versus distance profile for the sizing mission and the reference mission. An example is shown in Figure 3.

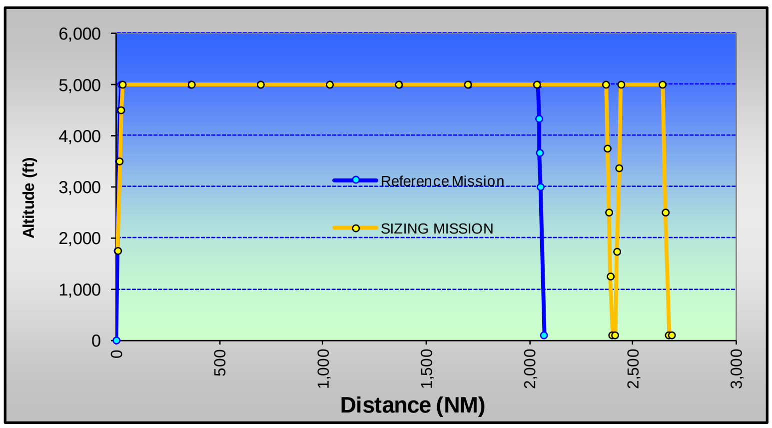


Figure 3. Example Sizing and Reference Mission Profiles

- Computations. The right side of the sheet does flight segment-by-segment calculations of the active airship. Computations are divided into two sections: sizing mission and reference mission. Each mission is divided into four climb segments, seven cruise segments and four descent segments. Results are provided for the mission, flight conditions, speeds and drag, weights, fuel and propulsion.
- Macro buttons. Excel macros are subroutines stored independently from typical cell contents that can be activated by clicking an on-screen button. Macros permit complicated computations and operations with a single button-click. The Performance page uses macro buttons primarily to converge a design. Different macros are used according to the constraints desired in the convergence.

3.2.2 Geometry 1

The Geometry 1 page is used to precisely define single-lobe airship envelopes. The defined shape is used for many calculations pertaining to the envelope. The shape can also be exported as a Virtual Reality Markup Language (VRML) file or as a CATIA-format file for manipulation in the CATIA computer-aided design package.

When this page is opened it contains geometry from the active airship selected on the Performance page, if the selected airship is a single-lobe design. Modifications to the envelope geometry are automatically relayed to the Performance page and other pages and are reflected in subsequent sizing computations.

Single-lobe envelopes are assumed to be laterally symmetric. They are defined by a reference maximum half-breadth (MHB) line and a series of lateral-vertical cross sections. The MHB reference shape is defined as a series of three linked conic sections defined by a starting point, corner point, end point and rho value that specifies curvature. An example maximum half-breadth reference definition is illustrated in Figure 4. The defining points are shown as yellow circles.

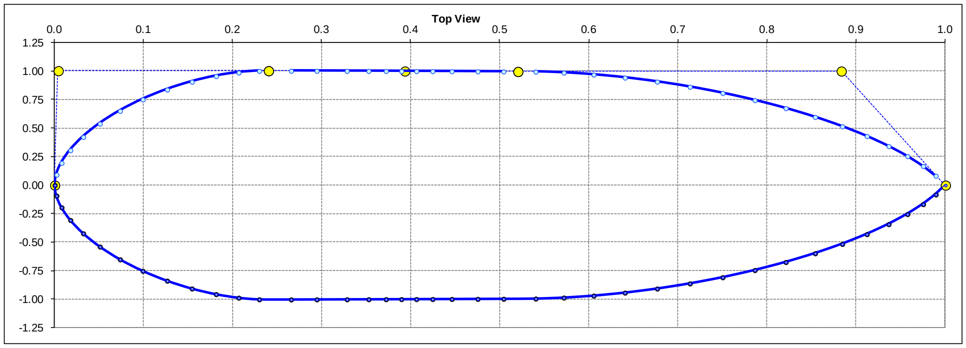


Figure 4. Example Maximum Half-Breadth Definition (ZPG-3W)

These cross sections are defined as upper and lower conic sections. Each conic section is again defined by a starting point, corner point, end point and a rho-value that specifies curvature. The proportions of the cross sections can be manipulated to change the airship's width-to-height ratio. An example cross section is shown in Figure 5. Its defining points are shown as green circles.

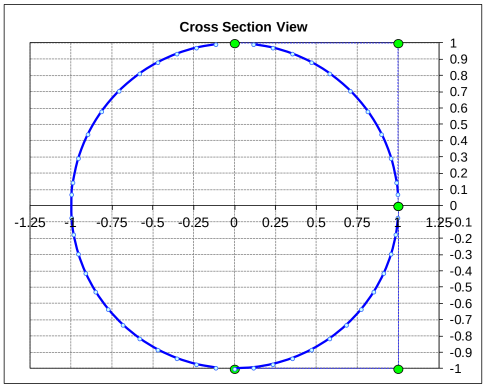


Figure 5. Example Cross Section Definition (ZPG-3W)

Because each cross section is individually controlled it is possible to achieve a wide range of single-lobe envelope shapes. Some possible cross section variations are illustrated in Figure 6.

An example envelope demonstrating how individual cross sections can be manipulated is shown in Figure 7.

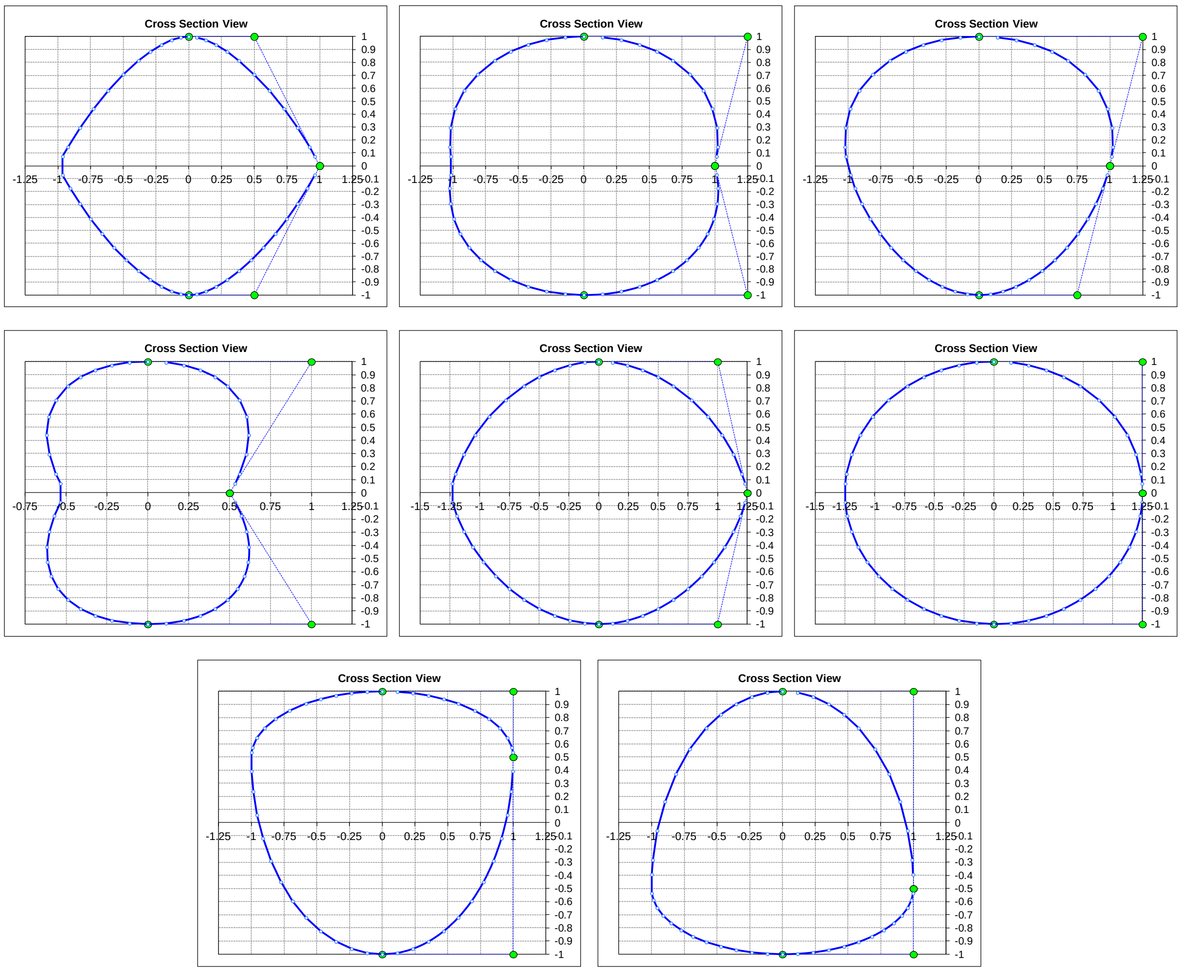


Figure 6. Example Single-Lobe Cross Section Shapes

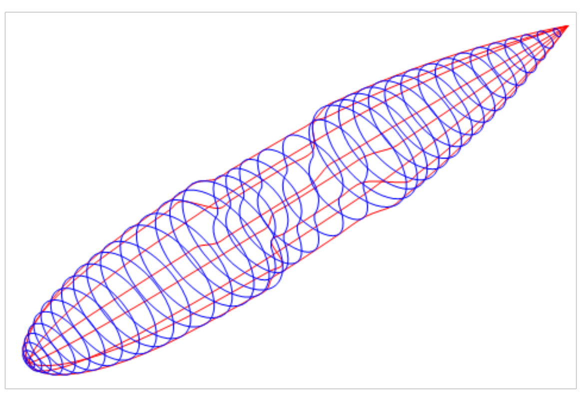


Figure 7. Example Envelope with Modified Cross Sections in the Mid-Section

Envelope geometry can be exported in the VRML format and in a CATIA format.

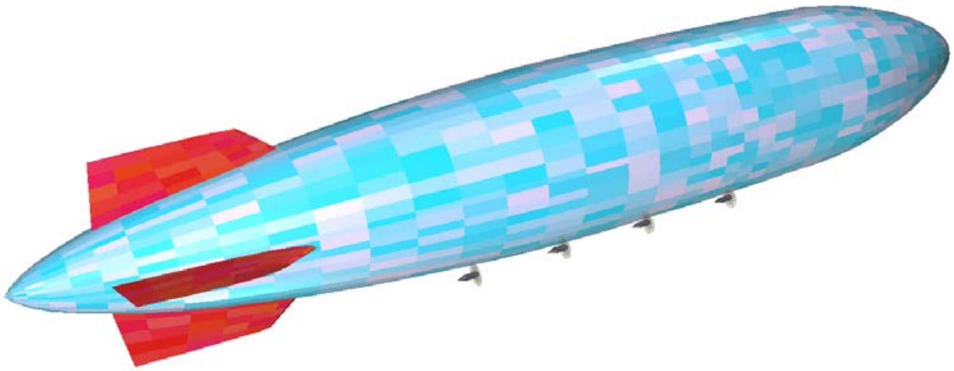


Figure 8. VRML Render of the USS Macon

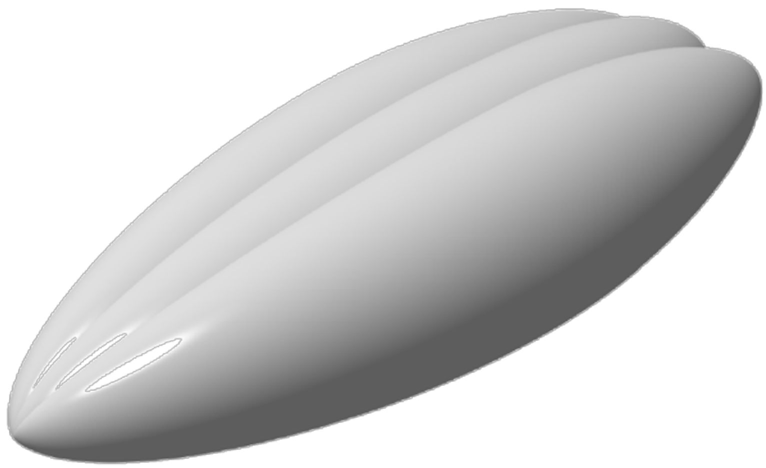


Figure 9. CATIA Render of Trilobe Envelope

Key outputs of the Geometry 1 page are overall length, maximum vertical diameter, wetted area, total volume, and longitudinal center of volume.

3.2.3 Geometry 2

The page Geometry 2 is used to define multiple-lobe airship envelopes. Multiple-lobe envelopes may provide a shape that is generally wider than deep. This may reduce induced drag for hybrid airships that rely on a combination of buoyancy and aerodynamic lift to fly. This page can generate envelopes with one, two, three, or four lobes, but single-lobe envelopes are better defined using the Geometry 1 page.

When the Geometry 2 page is opened it contains geometry from the active airship on the Performance page, if the active airship has a multilobe hull. If geometry is modified on the Geometry 2 page, changes are relayed to other pages, influencing subsequent calculations.

Geometry 2 assumes lateral symmetry so only one or two lobes are defined. The lobes are assumed to circular in cross section, reflecting the non-rigid structural concept of multilobe airships. (Presumably, a rigid airship would use a smoother cross section with a more favorable area-to-perimeter ratio.) Furthermore, equal pressure is assumed in each lobe, resulting in a straight septum joining the upper and lower lobe intersections.

The lobes are defined by centerline and diameter distribution. The centerlines are defined by lateral and vertical offset from the vehicle centerline. A3D automatically finds the lobe intersections and creates a septum at each intersection.

Figure 10 shows an example centerline lateral offset plot for a three-lobe airship. The blue curve defines the offset for the outboard lobe. The zero offset of the inboard lobe results in a single center lobe. A similar set of inputs and plot is used to define the vertical offset.

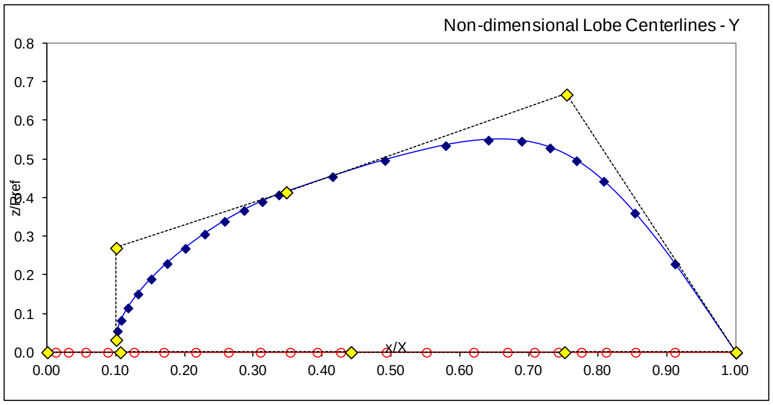


Figure 10. Example Centerline Lateral Offset Plot for a Three-Lobe Airship

A four lobe airship cross section is shown in Figure 11 along with the resulting full airship shown in Figure 12. In Figure 11 the center of the outboard lobe is shown as a blue circle; the inboard lobe center is a red circle.

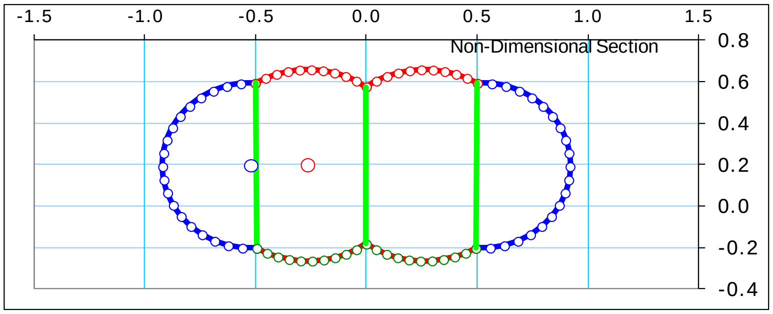


Figure 11. Example Four-Lobe Cross Section

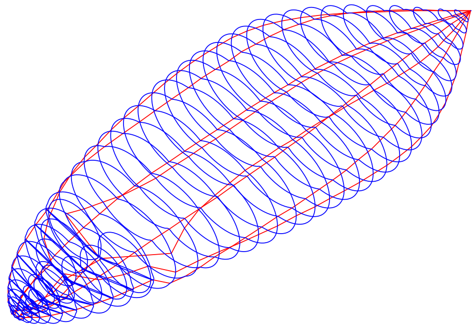


Figure 12. Example Four-Lobe Envelope from the Cross Section Shown in Figure 11

Geometry 2 also exports in VRML and CATIA formats.

3.2.4 Layout

The layout page is used to define the shape and locations of up to eight engines, propellers, pylons and fins. Definition may be performed at coarse and finer levels. Major adjustments such as prop diameter or fin span are made in the coarse mode – finer aspects of each component adjust parametrically with changes in the coarse values. Fine tuning may be done to more precisely define the shape of each component. The coordinates and weights of discrete additional masses are also specified on this page.

When the Layout page is opened it is populated with characteristics from the active airship on the Performance page. Changes to characteristics on the Layout page are relayed to Performance and other pages for use in subsequent calculations.

A selectable view of the airship envelope is provided with the specified components and, optionally, discrete masses. Discrete masses are automatically labeled in the view as shown in Figure 13.

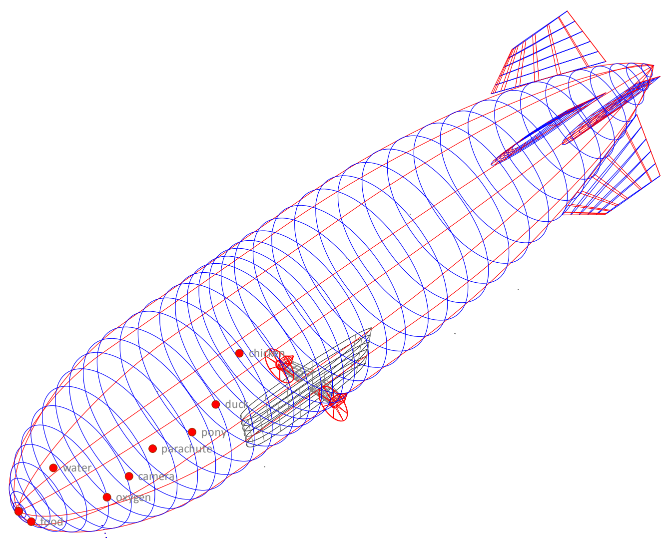


Figure 13. Example Airship with Propulsion, Fins and Labeled Discrete Masses

3.2.5 Stability and Control

The stability and control page analyzes the vehicle's geometry to estimate the handling qualities of the proposed design. In particular the page performs a tail sizing analysis, trims the aircraft at various conditions, produces linear bare airframe models, and performs non-linear simulations of vehicle response to perturbations.

For the most part, inputs to this module are automatically entered from other pages in the tool. These inputs pertain to properties of the ballonet, envelope aerodynamics, fins, propulsion system and excess drag.

Outputs include plots that permit the user to properly size the vertical and horizontal fins, estimate turning radius and trim the aircraft.

3.2.6 Main Weights

The Main Weights page calculates airship mass properties from inputs derived primarily from the Performance page. Calculated mass properties are provided in some detail in three major categories: operating empty weight, consumables and enclosed lifting gas and air. Mass properties for each component are provided in terms of mass, center of gravity (in three dimensions), characteristic dimensions (for inertia), moments, and products of inertia, airship weight in pounds per foot along longitudinal axis. Mass properties for the airship as a whole include mass, center of mass, center of buoyancy and mass moment of inertia.

Manual inputs to this page focus on the longitudinal location of the center of gravity of selected components.

3.2.7 Section Weights

The Section Weights page compiles mass properties from Main Weights per foot along the length of the airship. Running moments from the airship's empty weight, helium, and load are calculated. This is valuable to the designer because the end value of the running total loaded moment should be close to zero – this indicates an airship in balance. An out-of-balance airship must be reshaped to bring the loaded center of gravity in line with the center of buoyancy.

An example plot of running moments is shown in Figure 14. As shown, the running total loaded moment approaches zero at the tail of the airship. This indicates a nearly-balanced airship. If the solid blue curve falls below zero at the tail, the airship is heavy and vice-versa. This indicates to the designer the need to rearrange airship geometry or components to reach a balanced condition. The dashed blue line is scaled to always return to zero running moment for use with the structures module.

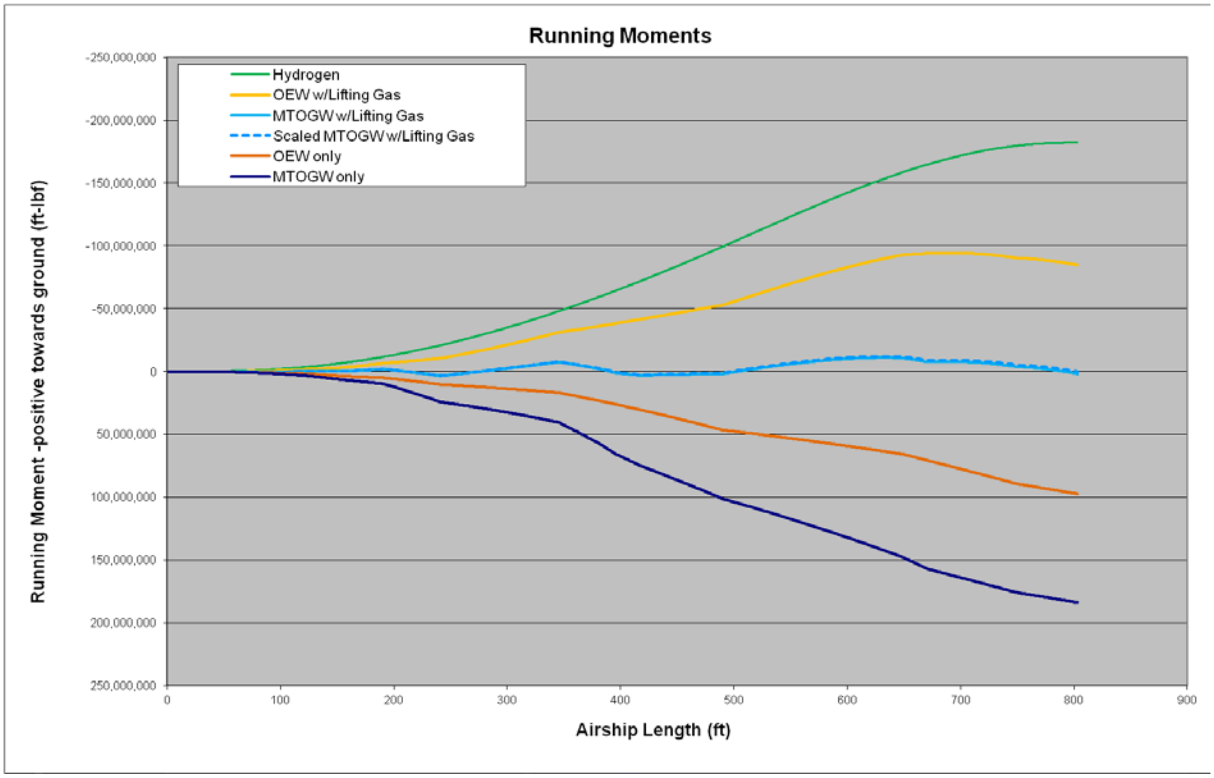


Figure 14. Plot of Running Moments versus Airship Length

3.2.8 Lifting Gas

The Lifting Gas page defines lifting gas properties based on the lifting gas selected for the active airship on the Performance page. A3D permits only two lifting gases: helium and hydrogen. Air properties are also tabulated.

This page also provides a table of kinematic viscosity as a function of altitude. This is used to calculate surface Reynolds numbers used in drag estimates.

3.2.9 Propulsion Tanks

The Propulsion Tanks page is used to size and weigh fuel tanks for the propulsion system. The user specifies tank geometry and material. The resulting tank volume is compared with the required volume from the Performance page and is adjusted as needed. The resulting tank system weight is transferred to the Main Weights page.

3.2.10 Cargo Bay Weights

The Cargo Bay Weights page is used to estimate the weight of the airship's cargo bay, if there is one. Weights are estimated as a combination of simple structural buildups and specified areal weights.

Many inputs to this page are specified on the Performance page – these vary according to the selected active airship. The key output from this page, total cargo bay weight, is transferred to the Main Weights page.

3.2.11 Air Cushion Landing System (ACLS) Weights

ACLS dimensions and weights are estimated for airships employing this concept.

ACLS, as employed on some airships, is a form of landing gear that in one mode resembles a hovercraft attached to the bottom of the airship. In this mode, the ACLS is pressurized with fans to lift the airship and provide a low-friction means of motion along the ground. This mode is useful for airships that are less than fully buoyant. It can enable taxi, takeoff and landing "roll". In a second mode, ACLS can provide suction, holding the airship firmly against the ground surface. This mode enables the airship to be docked at locations without docking infrastructure such as a mast. The suction mode is useful during cargo transfer operations and is especially useful when the airship is positively buoyant as well as in windy conditions.

The ACLS page estimates the capacity and weight of an ACLS based on its dimensions and operating conditions. Dimensions of the ACLS are estimated on the basis of airship geometry. Capacity of the ACLS is tied to suction and lifting pressures as well as resistance to sideslip and tip-over in a cross wind. ACLS weight is estimated with a historical algorithm and is transferred to the Performance page.

3.2.12 Aerodynamics

The Aerodynamics page estimates drag for the active airship and relays this back to the Performance page.

Drag is estimated for fins, pylons and nacelles with a component-by-component drag buildup. This buildup is sensitive to component geometry and Reynolds number. The drag of the airship envelope is estimated on this page only for single-lobe, axially-symmetric forms. Biconvex and multilobe envelopes are estimated on the following two pages.

3.2.13 Biconvex CFD

This page estimates the lift, drag and moments for a biconvex airship envelope. A biconvex envelope is characterized by cross sections with upper and lower surfaces formed by arcs with a sharp chine at the maximum half-breadth. Such an envelope can be made with a perimeter frame and otherwise unsupported, inflated skins.

Drag estimates of biconvex envelopes are based on CFD runs of a matrix of envelopes. These are varied in length-to-width ratio and length-to-average depth ratio. This matrix is shown in graphic form in Figure 15.

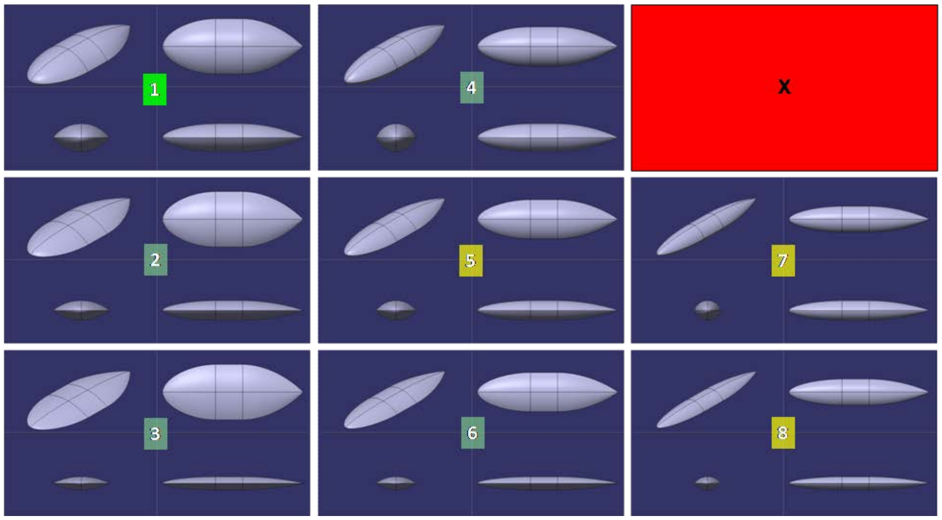


Figure 15. Matrix of Biconvex Airship Envelope Forms

CFD runs for each of the eight forms varies altitude and angle of attack. Forces and moments are the product of the effort. These are interpolated according to the biconvex proportions selected on the Performance page. Results are fed back to the Performance page for using in sizing and performance estimates.

3.2.14 Trilobe CFD

This page is similar in concept to the biconvex CFD page described above (Section 3.2.13). Its purpose is to estimate lift, drag and moments for a trilobe envelope.

Again, CFD runs on a matrix of envelopes are used as the basis for aerodynamic estimates. This matrix varies length-to-average diameter and length-to-height ratio as shown in Figure 16.

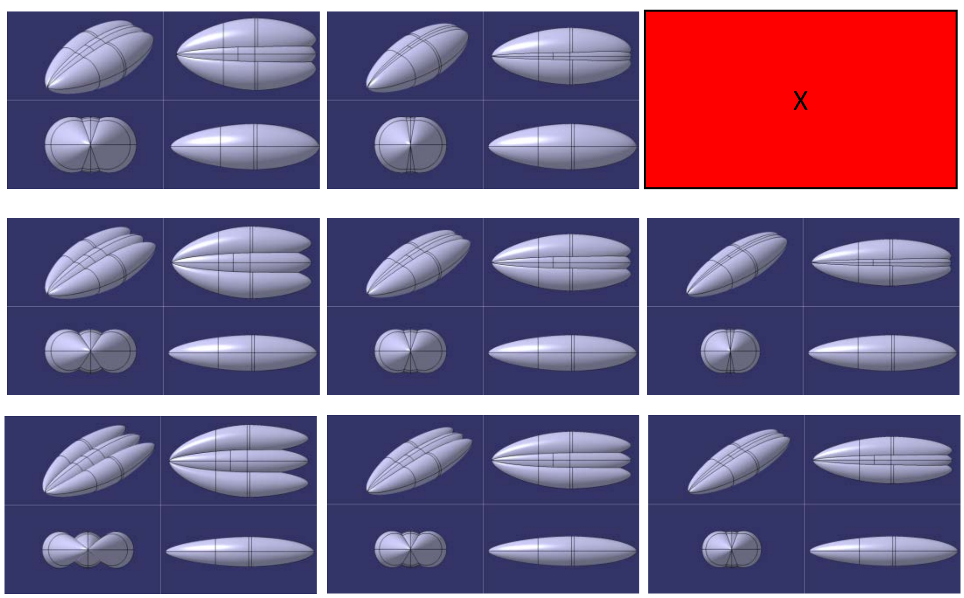


Figure 16. Matrix of Trilobe Airship Envelope Forms

For each of the eight forms, angle of attack is varied from zero to 30°. Forces and moments are recorded and are interpolated according to the proportions of the active multilobe airship on the Performance page. Results are passed back to the Performance page for its use.

3.2.15 Aero Loads

This page is based on additional data from the series of CFD runs described above (Sections 3.2.13 and 3.2.14). The additional data reports the lift force along the length of the active airship envelope according to its proportions and angle of attack. The result is used to estimate loads and moments on the envelope.

Two different general envelope forms are provided: trilobe and biconvex. Eight variations in proportions are provided for each general form. Lift force distributions are provided for these 16 runs at two angles of attack, 3° and 30°, giving a total of 32 columns of data. These are interpolated for specific flight conditions.

3.2.16 Loading

The Loading page pertains to the structural load imposed on the envelope by the combined forces of empty weight, payload, buoyancy, and aerodynamic loads. The primary output from this page is the bending moment imposed on each longitudinal station for each aerodynamic load case. This is used to estimate the needed envelope structure and the weight thereof. Figure 17 shows in graphic form the combined loads for a trilobe configuration.

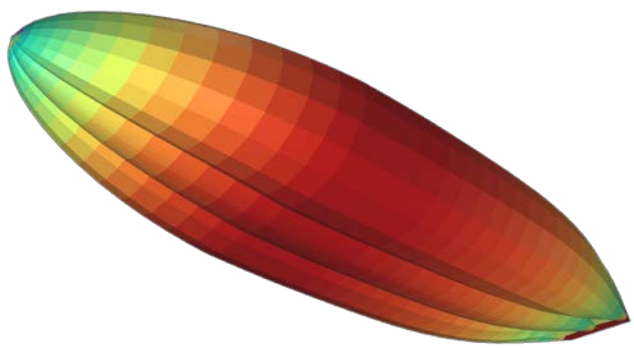


Figure 17. Combined Aerodynamic and Inertial Loads Shown by Color

3.2.17 Structures Definition

The structures definition page contains airship geometry coordinates that are used for a structural analysis of the airship hull. The material properties at each longitudinal station are displayed, as defined on the Performance sheet. After running a structural analysis from the Control Sheet, the maximum stresses calculated for each panel are output below the geometry definition on the Structures Definition sheet. The structural weight of the vehicle is calculated based on the minimum structural material required to meet the input stress allowables.

3.2.18 Propulsion

The Propulsion page calculates propulsion system characteristics for estimating vehicle performance. Key characteristics include maximum available thrust and fuel consumption versus delivered thrust.

The calculations divide the propulsion system into a core and a propulsor. The efficiency of each is independently estimated; their product is the total propulsion system efficiency. Fuel flow is proportional to thrust power divided by propulsion system efficiency. Thrust power is the product of thrust and airspeed.

Baseline core efficiency and power is defined by the user. These values are adjusted to account for altitude, throttle setting, and Mach number. These adjustments may be fine-tuned by the user.

Propulsor thrust and efficiency are estimated using induced loss methods in combination with estimated internal losses. A separate method is used to calculate static thrust.

Although airship propulsors typically work within the flow field of the airship envelope and may work within the boundary layer, propulsion characteristics are presently estimated as if they are operating with frees stream flow.

3.2.19 Mission and Wind 2

This section describes two pages of the tool, Mission and Wind 2.

The Mission page flies the active airship in wind to determine its performance in a more realistic environment. The user specifies season, time of day, origin and destination, and cruise altitude. Wind is then interpolated from a historical database contained on the Wind 2 page. This global database is an average of wind speed and direction by season or by year divided into 20,756 regions 2.5° latitude by 2.5° longitude at four altitudes: 9880, 13,800, 18,280 and 23,560 feet. A global map with winds for the selected cruise altitude and season is presented to the user. An example of this map is shown in Figure 18.

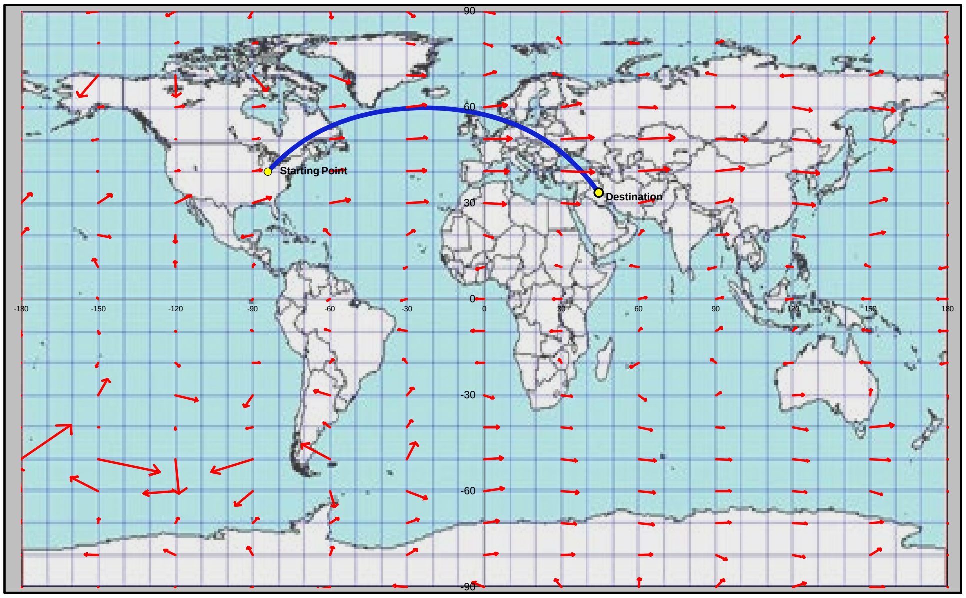


Figure 18. Global Map with Wind Velocity, Origin and Destination, and Route.

The Mission page output is also used on the Solar page (Section 3.2.21) for computing sun angle and resulting solar power.

An important limitation of the Mission page is that the airship path follows the great circle route. While this minimizes the ground distance, the air distance and fuel burned are probably greater than necessary.

3.2.20 Buoyancy Compensation

The Buoyancy Compensation page pertains to buoyancy compensation provided by removing lifting gas from ballonets and compressing it within a cylindrical cloth pressure vessel. This results in less lifting gas volume and reduced buoyancy. This, for instance, can compensate for variations in fuel load or payload.

Key inputs to the page are the pressure vessel geometry and gauge pressure as well as material properties. Key outputs are pressure vessel and pump system weights and the energy and power required to compress the lifting gas.

3.2.21 Solar

The Solar page pertains to envelope-mounted solar panels intended to provide photovoltaic solar power to the airship for propulsion, systems or payload operation.

Key inputs are the solar panel characteristics including weight, efficiency, and fraction of airship envelope area covered. Key outputs are the total array weight and energy provided over the course of a mission.

The Solar page uses the flight specified on the Mission page to estimate solar energy received. The specified flight is divided into segments. For each segment, the time of day, latitude and longitude are known, enabling an estimate of solar energy received.

An important limitation of this page is the simplifying but incorrect assumption that the solar array is oriented in a horizontal planar array instead of being conformal to the airship's surface.

3.2.22 Internal Combustion Engine

The Internal Combustion Engine page pertains to the design and characteristics of reciprocating piston engines. It has no direct user inputs or outputs – instead it is used by the Propulsion page. Its most important function is to adjust the engine size according to supercharger/turbocharger boost.

3.2.23 Survivability, Threat Detail and Countermeasures Detail

This section describes three pages that pertain to survivability: Survivability, Threat Detail, and Countermeasures Detail.

These three pages address airship survivability in the face of a range of threats from small arms, man-portable surface-to-air missiles and directed energy to air-to-air. The second and third pages provide guidance to the user for inputs to the Survivability page. Inputs to the Survivability page yield an estimate of susceptibility (probability of a hit), vulnerability (probability of a kill given a hit), and total encounter survivability result for each type of threat.

The pages also provide an estimate of the weight penalty of survivability measures.

4 RESULTS AND DISCUSSIONS

4.1 Concept Development

AFRL requested three study concepts: a Tactical Transport, Strategic Transport, and a Persistent Stare Platform. Not only does this exercise and stretch the tool, it also provides trends that show the user benefits of one configuration over another. Since the tool provides such a large number of options to adjust, the initial concept designs were performed with best guesses for how a near-term airship would be designed for that particular mission. While there is an option to use Hydrogen as a lifting gas, helium was chosen as the safer option in all cases. The non-optimized baselines were not fitted with solar power or air cushioned landing systems. Solar power was used on the optimized versions to reduce fuel costs, one of the primary drivers for airships. All designs did however carry water recovery systems and helium compression on the assumption that helium is valuable and not to be valved. Advanced technologies were reserved for the Technology Assessment.

The tactical transport was chosen for the first study due to its smaller payload and range. Its requirements were aligned with the C-17's capabilities, namely a range of 2,800 nautical miles and a payload of 170,000 lbm. The cargo bay was scaled up from a C-17 to distribute the load along the length of the airship structure and provide greater volumetric potential.

Some assumptions were made for both tactical and strategic transports. Rigid airships were used after runs with semi-rigid or non-rigid airships did not close due to internal air pressure needed to withstand stresses. This is consistent with designs of the 20th century where non-rigids and semi-rigids were limited to approximately 400 feet long. Traditionally, large airships tend to have length-to-diameter (L/D) ratios between 5.9 and 7.8. This was due primarily to the limitations of their hangars. The Cargolifter hangar in Germany, which allows for much taller and wider airships, was taken into consideration when checking cross section dimensions. The top speed chosen to size the engines was 84 knots. The maximum pressure altitude was set to 5,000 ft. While the current state of software does not model the ability to climb higher temporarily, using lifting gas compression and dynamic lift, it is feasible that these transport airships could do so if needed.

As a foundation for starting the conceptual design for the three study missions, we performed a survey of three envelope species on a whole-airship basis. These were axially-symmetric (round), biconvex and trilobe. These were examined over a range of L/D to characterize volume, fuel burned, and cost. Figure 19, Figure 20 and Figure 21 below show the three species and variations on L/D that correspond to the three graphs that follow.

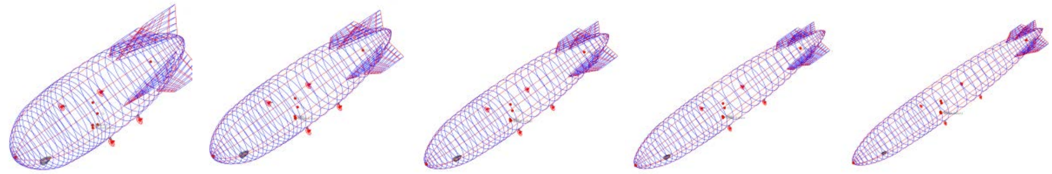


Figure 19. Axially-Symmetric Airships with Varying Length-to-Diameter Ratios

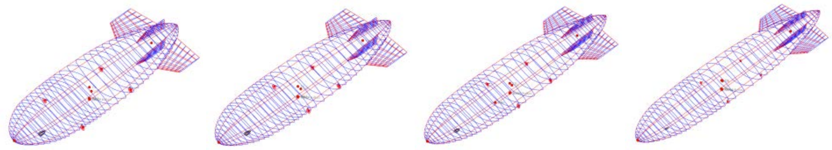


Figure 20. Biconvex Airships with Varying Length-to-Diameter Ratios

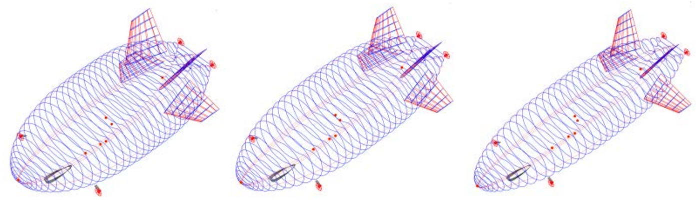


Figure 21. Trilobe Airships with Varying Length-to-Diameter Ratios

The summary graphs shown below in Figure 22, Figure 23, Figure 24 highlight a few key points. Airships have a performance and volume sweet spot at an L/D of around 4.5. This is due to less surface drag, lower bending moments, and better volume to surface area ratios. The biconvex designs, with lower bending moment of inertia due to less depth, tend to have an upper limit on how slender they can be. This can be seen on the fourth data point. Similarly, round hull airships are subject to a similar trend. Biconvex airships also are not suited to lower L/D due to larger horizontal fins needed for pitch stability. The trilobe airships use a much lower range of L/D by definition in order to achieve dynamic lift.

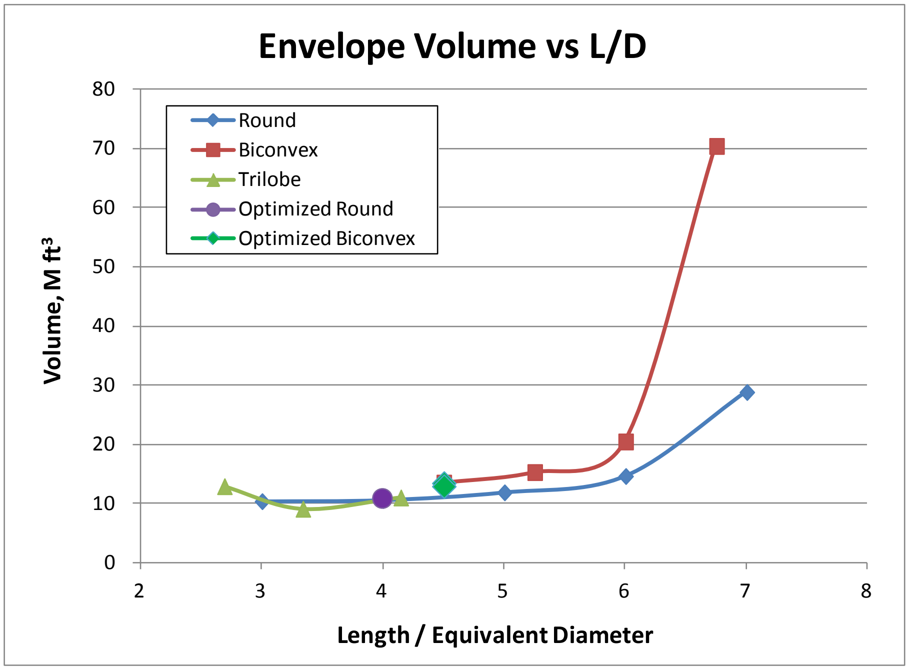


Figure 22. Envelope Volume versus L/D for Three Envelope Species

While trilobe airships can be smaller due to using more dynamic lift, they burn more fuel.

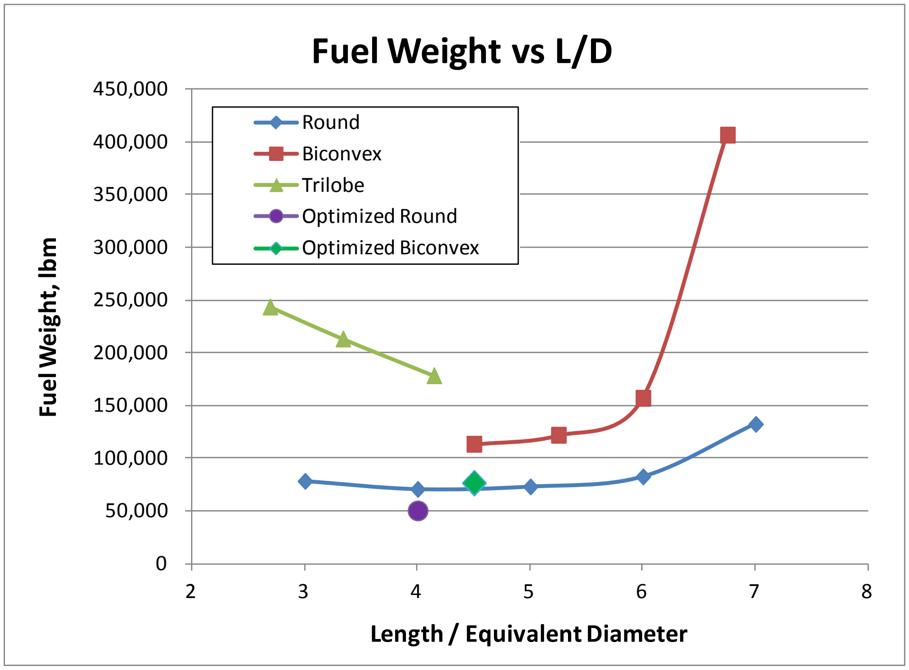


Figure 23. Fuel Weight versus L/D for Three Envelope Species

Note the trilobe costs start outside the graph due to larger engines needed. The cost module has limitations due to the current set of engine curves which grow exponentially with horsepower. This is an error in the method and needs improvement.

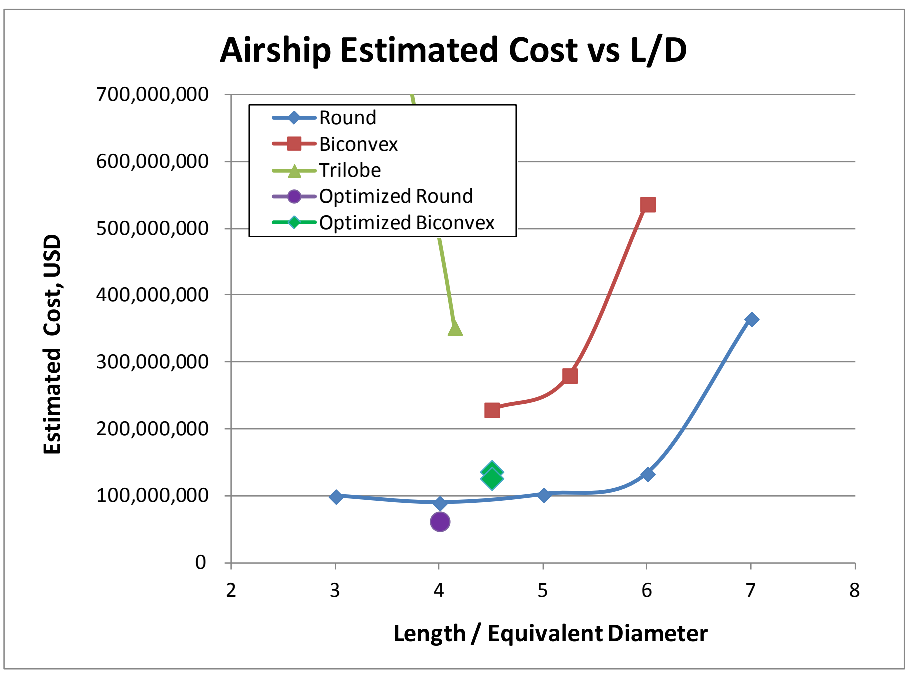


Figure 24. Estimated Cost versus L/D for Three Envelope Species

4.1.1 Tactical Transport Case

Using the baseline graphs above as a starting point, one round and two biconvex models were created for the tactical transport. The same range of 2,800 nm and 170,000 lbm payload were used. With solar power added to these configurations, the fuel weight decreased, as compared to baseline designs within the same family. Even though biconvex airships perform slightly less favorably than their round hull counterparts, they were kept in the mix due to other considerations such as superior surface orientation for solar power and increased lift coefficients in case more dynamic lift is necessary. However, the biconvex also requires larger horizontal fins to stabilize higher pitching moments in flight. Fins were approximately sized, using the stability and control module, to LZ-129 type stability data. To lighten each type of tactical transport, cargo bays were lengthened but reduced in width and height to be more in line with the C-17's. This reduced the bending moment by spreading the payload longitudinally.

The resulting optimized axially symmetric (round) tactical transport had a length of 695 ft, a diameter of 174 ft and a fuel weight of 50,000 lbm. This is illustrated in Figure 25 in the direct-from-Excel wireframe form and in a black-and-white VRML rendering. Note that the VRML rendering is surfaced and is not transparent like a wireframe. Also, in a VRML viewer the rendering may be easily rotated to provide different views.

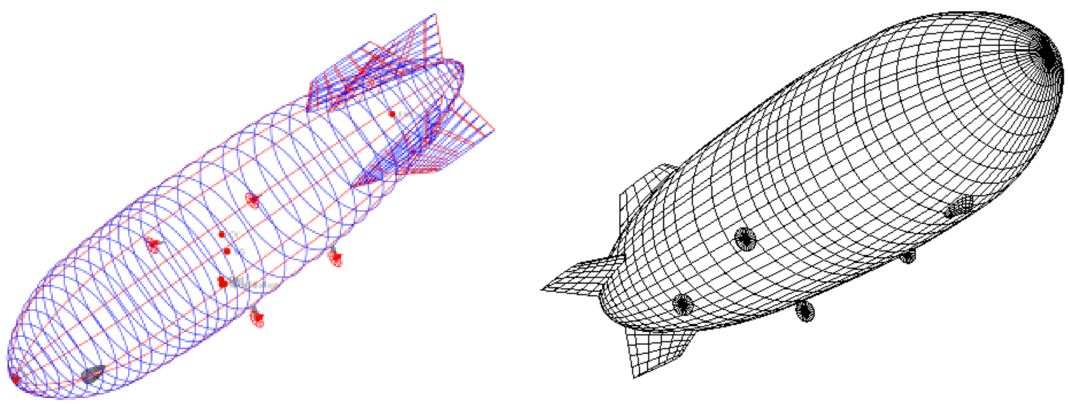


Figure 25. Axially-Symmetric Tactical Transport

Two variations of the biconvex configuration were studied for the tactical transport mission. The first biconvex configuration is shown in Figure 26 in Excel and VRML formats. The first biconvex tactical transport has a length of 831 ft, width of 277 ft, depth of 139 ft and a fuel weight of 76,000 lbm.

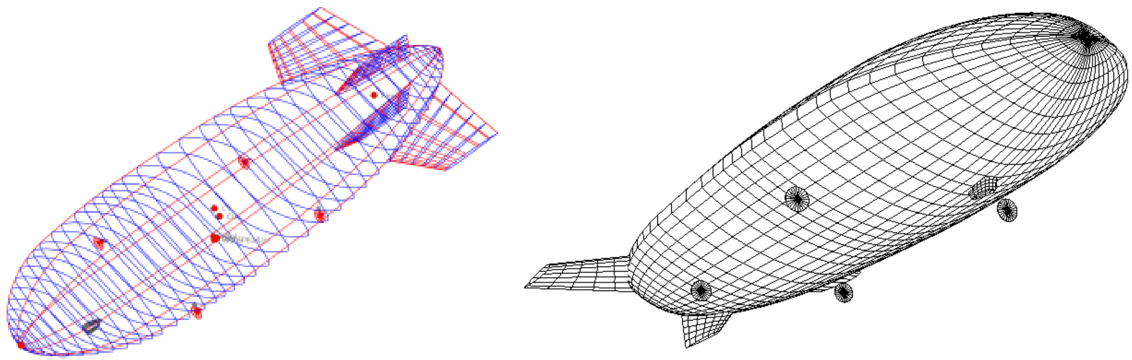


Figure 26. Biconvex Tactical Transport – Option 1

The second biconvex airship is shown in Figure 27. Its characteristics are: length = 820 ft, width = 219 ft, depth = 156 ft, fuel = 77,000 lbm.

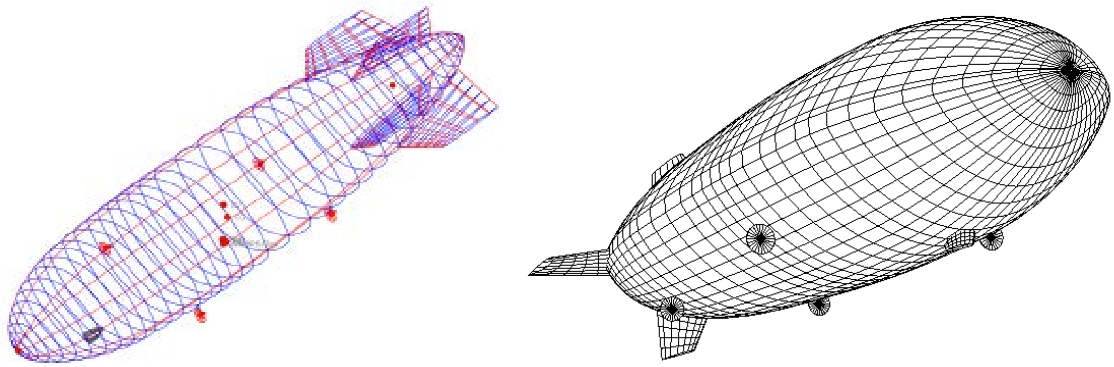


Figure 27. Biconvex Tactical Transport – Option 2

4.1.2 Strategic Transport Case

The strategic transport was based on the second biconvex tactical transport as a middle ground configuration. The requirements used for this case were loosely aligned to a C-5 transport. A range of 6,000 nautical miles with a payload of 300,000 lbm was used.

Its characteristics are: length = 997 ft, width = 266 ft, depth = 190 ft, fuel = 189,000 lbm.

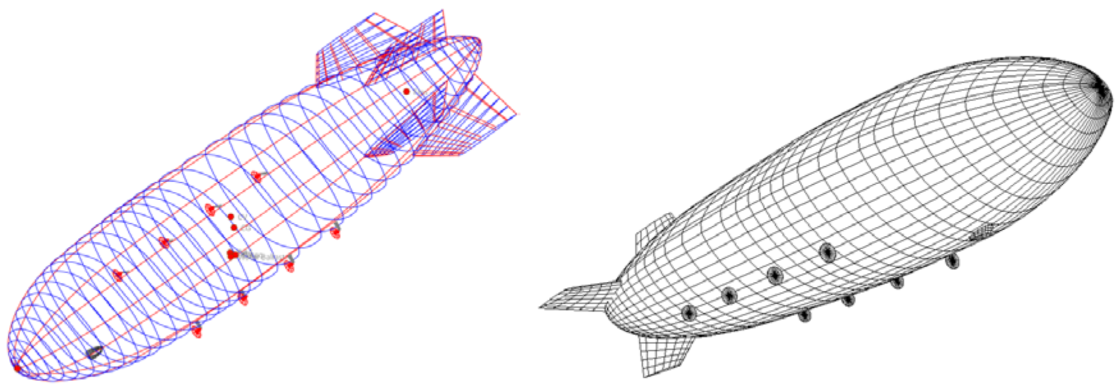


Figure 28. Biconvex Strategic Transport

In both tactical and strategic transport cases, the Cargolifter hangar would be required. The fuel used by transport airships is roughly a third to half of that of comparable traditional airlifters. All were sized to be able to offload cargo vertically within 120 minutes.

4.1.3 Persistent Stare Platform/Intelligence Surveillance, Reconnaissance (ISR) Case

Two cases were run for persistent ISR. Round hulls were picked in both cases since that is the most efficient hull shape for endurance. Solar power for daytime is used to cut fuel consumption. The same L/D of 4 was chosen for its blend of low drag and volumetric efficiency. All forms of landing gear were removed to lighten the vehicle. Batteries were too heavy to be used in either case.

The first case was for a 21-day LEMV-type mission at 20,000 ft with a 2,500 lbm payload. This configuration assumes a 10-percent high-altitude weight reduction to mooring equipment, fins, envelope, and gas bags. A cruise speed of 30 knots with a top speed of 80 knots was used. With a low cruise speed of 30 knots, and its small size, it only needs solar cell coverage of 10% of the upper half of the hull to cruise. The optimized airship is shown in Figure 29.

Its characteristics are: length = 315 ft, diameter = 79 ft, fuel = 11,420 lbm.

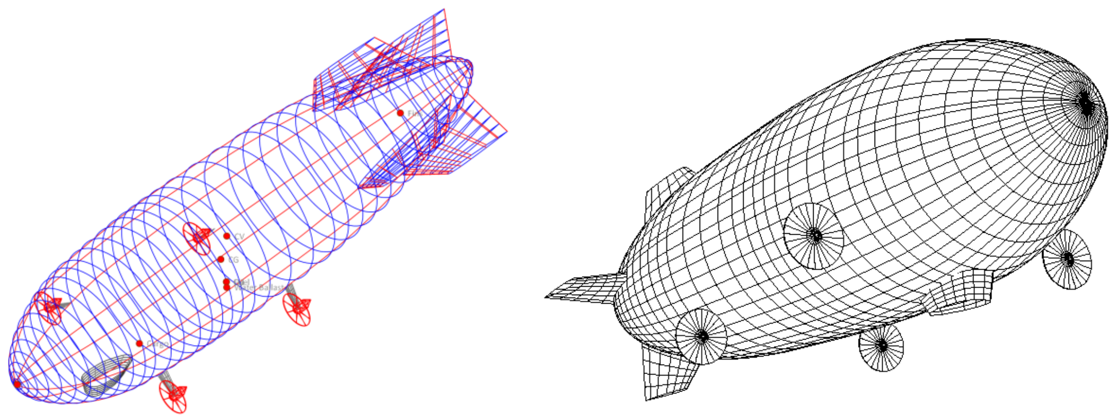


Figure 29. Axially-Symmetric ISR Airship for 20,000 ft Altitude

The second case was for a High Altitude Long Endurance (HALE) type mission at 60,000 ft, with a 2,500 lbm payload for 60 days. This configuration assumes a 40% high altitude weight reductions to mooring equipment, fins, envelope, and gas bags. A cruise speed of 30 knots with a top speed of 50 knots was used. This mission assumes no pilot. With a low cruise speed of 30 knots, it needs solar cell coverage of only 20% of the upper half of the hull. This airship is shown in Figure 30.

Its characteristics are: length = 826 ft, diameter = 207 ft, fuel = 28,300 lbm.

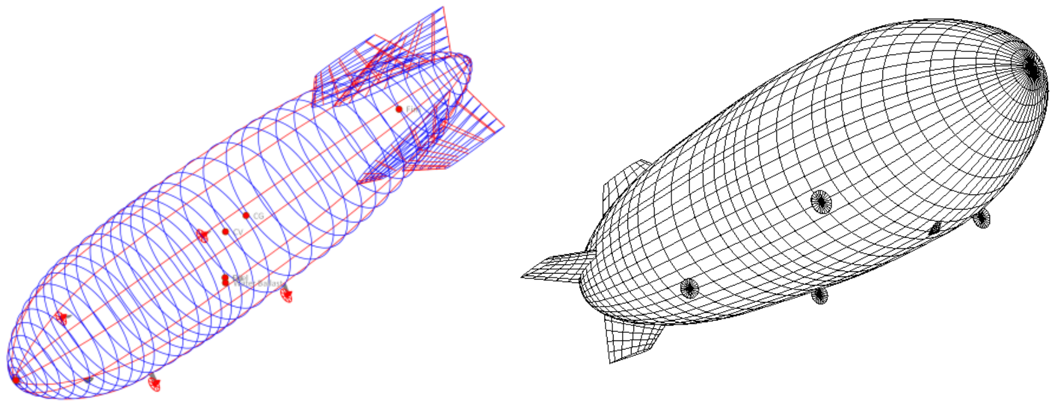


Figure 30. Axially-Symmetric ISR Airship for 60,000 ft Altitude

Currently, the only platform capable of extended station keeping within the atmosphere is an airship, provided the average winds are less than the cruise speed and gusts are less than the maximum speed. With the correct design concept and accurate global wind models, an airship can be the most fuel efficient ISR vehicle available.

4.2 Technology Assessment Results and Discussion

To trade future technologies, single technologies were varied on the baseline axially-symmetric tactical transport design by reducing subsystem weights 10%, 20%, and 30%. The results are displayed in Figure 31 and Figure 32 below in terms of envelope volume and fuel weight, since fuel efficiency is one of two primary reasons for developing airships. Note that the battery line does not line up with the red baseline. This is because the battery option was added to the baseline, which drove down the fuel weight but increased the envelope weight to lift the added battery weight. The slope of the line determines each subsystem's weight reduction effectiveness on fuel and envelope volume.

To save the most fuel, reducing engine specific fuel consumption is crucial. Reducing specific fuel consumption (SFC) by 10%, 20%, and 30% saves 11.0%, 21.8%, and 32.3% fuel respectively. However, reducing an already low SFC may not be easily realized. Helium compression is probably the most realistic and attractive advanced technology available, in that it solves the offload issue and is not integral to the main structure. As battery energy density increases, it is the next most important technology available. Not only does it enable solar power to be useful during night operation, but it maintains weight unlike expendable fuel. At some point, the energy density will be sufficient to provide full night time capacity as well as charging at destinations to reduce solar cell area. All other weight reductions do very little to affect the fuel consumption. For the airships studied here, the benefit was a decrease in the footprint of the solar cell area. Improving current solar cell efficiency is not effective unless you need more power.

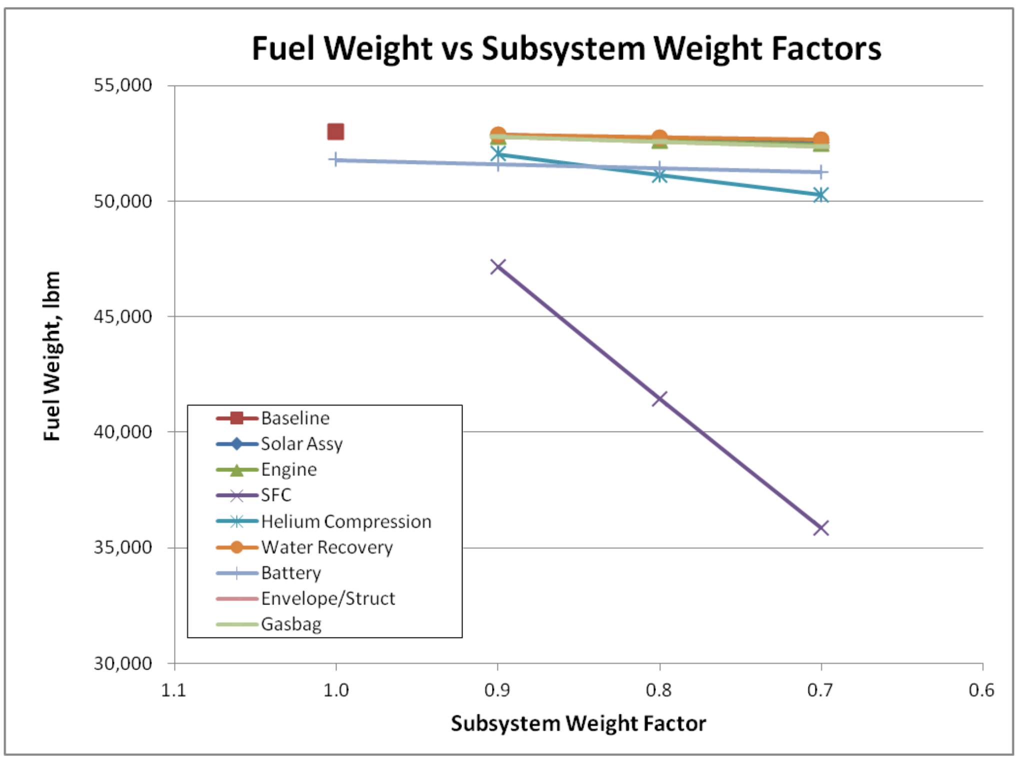


Figure 31. Fuel Weight versus Subsystem Weight Reduction

Reducing envelope volume is one measure of cost since it drives the aerodynamic drag and dry weight. What is evident is that the subsystems that carry the most weight have the most advantageous slopes.

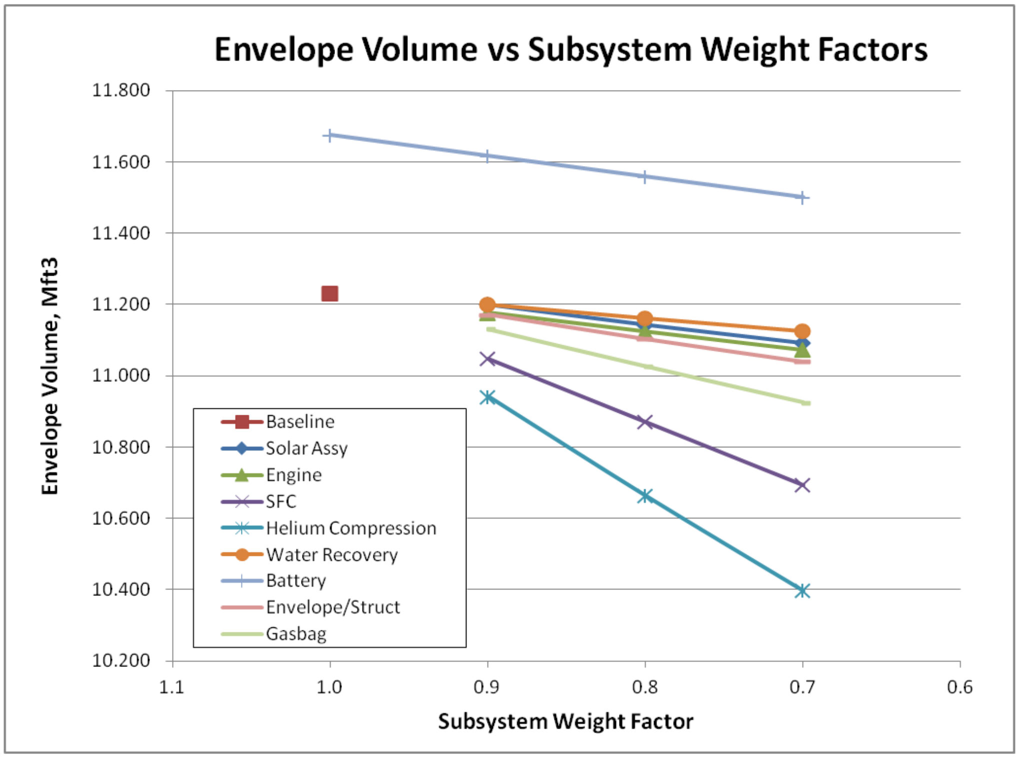


Figure 32. Envelope Volume versus Subsystem Weight Reduction

These technology assessments point out that the biggest strides made in airship efficiency may not be primarily in technology, but in good old-fashioned airship design. This point will be expanded upon in the conclusion.

5 CONCLUSIONS

An advanced airship analysis and design tool is created and described. This tool may be used to evaluate existing and proposed airships. It may also be used to design new airships. The tool requires relatively few inputs and provides approximate characteristics in little time. The tool is created in Microsoft Excel, permitting direct examination, simple modification, and diverse graphics.

The tool considers airship payload; aerodynamic lift and drag; buoyancy; stability and control; structural loads, materials and weight; mass properties including center of buoyancy and mass; and propulsion. The tool can be used to estimate the performance of a specified, fixed airship or can size an airship to provide specified performance.

Different envelope types can be evaluated. These include axially-symmetric, multilobe, and biconvex shapes. These can be formed with a wide range of proportions. Resulting aerodynamic characteristics are approximated from a database of computational fluid dynamics runs.

Performance is evaluated by running a multi-segment mission including climb, cruise, and descent. Sizing is accomplished with selected constraints on envelope size, propulsion, and range.

Section 4 and Section 4.2 show that careful selection of airship species and proportions have a greater impact on airship performance than advanced technologies. It is important to choose the right airship type and shape for the specific mission. No one type of aircraft can fulfill every mission – airships are no exception.

There are many areas to which an airship architect must pay attention. The most critical appears to be structural design. Since airships are very large and light, how one loads an airship is critical to its structural efficiency. Despite the ample volume available in many airships, weight implications of massive cargo bays must be recognized. Floor loading and weight distribution must be taken into consideration. Mass properties, aero loading, and ground handling are paramount to understanding the structural design. Engine choice is also critical since long duration missions, typical for airships, heavily influences the amount of fuel carried. This affects not only the helium volume needed to lift, but some combination of water recovery and helium compression systems. An airship design is much more integrated than an airplane and one must be careful to respect that. This supports the impetus for developing a conceptual level tool that is solid in its foundation with room to grow and the will to grow it.

Delivery of this tool indicates that a new capability has been achieved by the Air Force. The Air Force previously had very little in terms of LTA and hybrid aircraft analysis capability. Although the fidelity of this tool is low and intended for conceptual design analysis, it vastly improves Air Force analysis capability. By expanding into a new configuration space, more air vehicle alternatives for cargo transport and ISR missions can be generated and analyzed. These alternative concepts can be passed on to higher-level mission effectiveness studies that can show the impact of an airship fleet on mission effectiveness metrics, such as time to close, fuel burned, time on station, and cost.

6 RECOMMENDATIONS

6.1 Potential Tool Improvements

6.1.1 Solar

One A3D module pertains to energy contributions to the airship from photovoltaic cells. A practical airship would preferably conformably wrap some portion of the airship in cells to minimize installation weight and aerodynamic drag. This results in variations in solar power with sun angle and airship heading as some cells are shaded or angled to the incoming sunlight. It is a limitation of A3D that the computation of solar power does not account for conformal wrapping of the cells. Instead, the specified area of cells is mathematically assumed to be in the form of a horizontal, planar surface. The solar power result is thus sensitive to sun angle but not to airship heading. Furthermore, for some missions operating with low sun angles (at near-polar latitudes), such a horizontal orientation may be less effective than a more vertical orientation such as that on the side of an airship despite half of the cells being in full shade. This is an area for future development.

6.1.2 Cargo Loading Alternatives

The traditional heavy airlift method of rolling cargo on and off does not work well with airships. The airship frame distributes loads to minimize stress. A standard airplane cargo bay has a heavy floor to take localized loads from vehicle wheels. An airship may be better suited to a lift sling approach without a rigid floor.

6.1.3 Improved Buoyancy Compensation

While this tool does take into account methods for buoyancy compensation such as helium compression and water recovery, a more detailed study to predict time and energy required to perform the offload would be useful, as this is the key to making airships viable as cargo aircraft.

6.1.4 Wind

Due to low cruise speeds, performance of airships is heavily influenced by wind. Accurate estimation of real-world performance must account for the positive benefits of tailwinds and the adverse effects of headwinds.

A3D includes a module with average global wind speed and direction for four seasons or a whole year, at four different altitudes. This module enables the user to fly the airship between a specified origin and destination at a given altitude on a given day. A3D then computes the actual air distance the airship must fly over each of multiple flight segments, accounting for the local wind speed and direction. This can give the user an indication of the airship's sensitivity to wind. However, in this module, the airship is always and only flown over a great circle route between the origin and destination. The great circle route is unlikely to be as good as an optimized route that takes advantage of tailwinds and/or finds weaker headwinds in exchange for a longer ground-route distance. Good, in this case, may mean less fuel burn, a faster flight or perhaps minimum fuel burn within a specified time schedule.

An improved module could use more granular weather data. This could be real data, taken on specific days selected to represent both the spectrum of real weather and average weather when taken as a whole. Flight path could be optimized for a given weather day to provide the best outcome (fuel burn, speed or schedule for example). Such an optimization provides a more realistic estimate of airship performance than a great circle route and is much more realistic than simple still-air performance estimates.

6.1.5 Loads and Structures

Potential improvements include the addition of mooring and ground handling loads, and envelope stresses from altitude and attitude changes. Present loads derive only from straight-and-level flight. The addition of more complex conditions such as a climbing turn may improve fidelity.

6.1.6 Aerodynamic Database Improvements

Additions to the present database can include a wider range of envelope shapes as well as fins. This can permit interpolation from the database and avoid extrapolation, improving results.

6.1.7 Additional Configurations

The A3D tool can be strengthened by addressing additional configurations. Example configurations include the hybrid thermal airship and the flexible skin fixed wing airlifter. The hybrid thermal airship uses variations in gas temperature to control buoyancy and address changes in fuel or payload weight. The flexible skin fixed wing airlifter is, in essence, an inflatable aircraft, without buoyant gas. A notional illustration is provided in Figure 33.

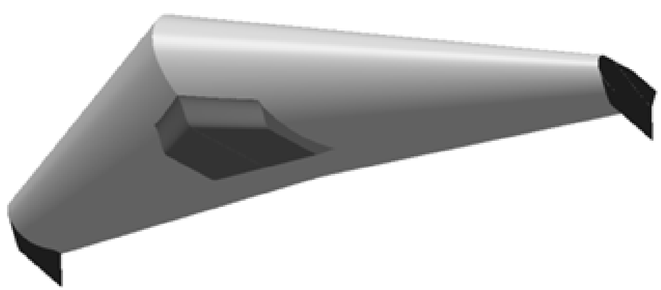


Figure 33. Flexible Skin Fixed Wing Airlifter

7 REFERENCES

~~1.~~ Gabriel Alexander Khoury, Airship Technology, Cambridge University Press, New York, NY, 2012.

2. Richard K. Smith, The Airships Akron & Macon, Naval Institute Press, Annapolis, MD, 1965.

~~3.~~ Christopher Chant, The Zeppelin, The History of German Airships from 1900 to 1937, Amber Books Ltd, London, UK, 2000.

APPENDIX
SOFTWARE USER MANUAL

A1 INTRODUCTION

The Advanced Airship Analysis and Design (A3D) Tool enables sizing and performance estimation of airship configurations. A3D is a conceptual design tool intended to provide rapid but approximate results suitable for preliminary sizing and comparison of alternative concepts. It is also intended to scrutinize design proposals in a field with few existing estimating methods. Checking the validity of airship claims is necessary to save a contractor from wasting valuable budget. A3D is quite flexible. It supports airships of a wide range of speed, altitude and configurations. It integrates almost all key aspects of airship design, including aerodynamics, stability and control, structures, weights and propulsion to provide a realistic performance estimate.

A3D's architecture enables the development of side-by-side alternative designs to permit easy comparison.

A2 TOOL CONCEPT

A3D is embodied within the Microsoft "Excel" spreadsheet program. Excel is chosen as a foundation for its ease of development, use and modification. Also, it permits clear plots and even 3-D wireframe images of the airships as they are formed by the user.

The intention of A3D is to provide the best possible accuracy with a limited number of user inputs (and within the project budget). To this end, A3D attempts to be more detailed and accurate in those areas that are more important to performance results. Fewer inputs and less programming effort have been directed to less important areas of the design.

In addition to the Excel, there is one Matlab Add-In necessary for the Stability and Control module. This file must be saved and compiled on the user's computer at the outset. It then runs within the Excel workbook when called upon.

A2.1 A3D Architecture

A3D is arranged in multiple, linked spreadsheet pages. A single main page, called "Performance" is the hub from which the spreadsheet is operated. All other pages support the Performance page. This arrangement is diagrammed in Figure A- 1.

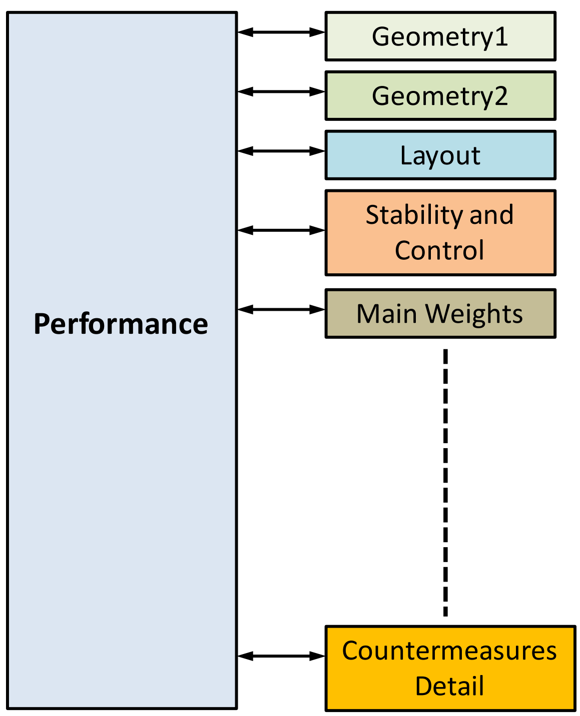


Figure A- 1. Diagram of Basic A3D Architecture

A key aspect of A3D's architecture is that the user may select one of many pre-entered airships for analysis. Each airship's key information is arranged in side-by-side columns. Selection of an airship not only selects a specific column of information but also controls the inputs on many of the supporting pages. Furthermore, many of the supporting pages' outputs are then also entered into the Performance page.

A3 GENERAL NOTES

A3.1 Excel Concept

The tool is based in Microsoft Excel. This spreadsheet program provides numerous benefits to the tool-maker and the tool-user. These include:

- Cross platform compatibility
- Stability over time with respect to computer, operating system and software updates
- Open architecture
- Ease of software creation and modification
- Easily implemented graphics

Excel software is structured geometrically into cells and pages. Excel may also have embedded Visual Basic code, known as “macros” that is separate from the cells and pages. Excel can also create complex graphics and plots. These features are described in the following sections.

A3.1.1 Cells

Each page of Excel is arranged on a two dimensional grid of individual “cells”. Each cell is identified by its location by its column and row labels. Columns are labeled by letter; rows by number. Cell A1 is the top left cell. Cell C4 is in the third column and fourth row.

Cells may contain only words, numbers or a single formula. The cell may display its words or numbers. For formulas, either the formula or the numerical result of the formula is shown, with the numerical result being the typical display.

Formulas reference other cells. These referenced cells may be numbers or formulas. Referenced cells may be on the same page, on another page in the same spreadsheet, or in any location on another spreadsheet. This tool is a single spreadsheet file – no additional spreadsheets are referenced.

A3.1.2 Pages

Spreadsheets may have multiple pages. These are accessed via “tabs”, named for each page, at the bottom of the spreadsheet. Pages streamline the organization of a large spreadsheet and speed navigation through the spreadsheet.

Formulas on any page may reference a cell on another page by including the name of the page in the reference. For example, on Page “Vehicle Layout”, Cell T3 on page “Geometry1” may be referenced as “Geometry1!T3”, where the “!” denotes the division between page and cell. For cells referenced on the same page, the page callout is not needed.

A3.1.3 Graphics

Excel may be used to generate a wide range of plots and graphics based on values and words in specified cells.

Most plots within the tool are conventional. However, the tool provides wireframe views of entire airships and airship components that are somewhat uncommon. The user can choose from three key orthogonal angles (top, side and front), an isometric view and two user-selected custom views. These views help the user to avoid input errors – errors are usually quickly spotted. They also assist in an "eyeball" assessment of the design.

A3.1.4 Macros

A "macro" is discrete subroutine that performs Excel operations beyond direct cell-to-cell calculations. Macros can be used to automate laborious or repetitive operations such as cutting-and-pasting. Macros can also be used to call Excel operations such as "Goal Seek" and "Solver" to accomplish very complex tasks. Most macros are activated by clicking on a labeled "button" on the spreadsheet.

It is easy to move cells within a page or from one page to another. Equations in other cells automatically update referenced locations so that they continue to reference the correct cells. This function works very well for cell-based equations. <u>However, the update function does not work for macros!</u> Many Excel macros perform operations on specific cells based on cell location. Moving the cells involved to another location does not automatically update the macro and will almost certainly ruin the macro's function. The spreadsheet tool provides no indication of cells referenced by macros. This means that changes to a spreadsheet with numerous macros requires great care. If possible, changes should be made without moving cells; additions should be made in blank areas of the page.

A3.1.5 Hide and Unhide / Grouping Cells

It may be helpful on some pages to hide or reveal columns or rows. This may allow the user to put cells of interest on the screen at the same time. To hide a contiguous series of columns or rows, highlight them by swiping on the column letters or row numbers. Right click to bring up a menu and select "hide". To "unhide", select the rows or cells on either side of the hidden ones, right click and select "unhide".

There are some areas in the spreadsheet in which rows or columns are grouped to facilitate more efficient viewing of the page. The user should be aware that grouped data, when collapsed, does not show up on charts and graphs. This can sometimes be mistaken for an error in the graphics.

A3.1.6 Preparations to Run

As mentioned earlier, in order to run the Stability and Control module, the user must do the following:

- Copy GNC_module_pkg.exe to a local location that the user will remember
- Install GNC_module_pkg.exe by doubling clicking the file
- Hit yes to all
- Wait for Matlab Compiler Runtime (MCR) to install, hit yes to all
- The executable will create a file in the same folder called GNC_module.xla
- Open the LTA tool in Excel and navigate to: Office Button -> Excel Options -> Add-ins -> Manage add-ins -> Browse -> Add GNC_module.xla
- Try running the macros.
- If you encounter: Error in GNC_module.Class1.1_0:

- Open the LTA tool in Excel and navigate to: Office Button -> Excel Options -> Add-ins -> Manage add-ins -> Browse -> Add FunctionWizard.xla
- In Excel, navigate to Add-Ins (on the ribbon) -> MATLAB Functions ->
- Make sure “I want to incorporate MATLAB component files into Microsoft Excel” is selected-> Click Ok
- Click Add (near Active Functions) -> Cancel -> Close
- Try running macros again.

Steps 1 through 6 should only need to be done once per user per computer. Steps 7 through 10 need to be done each time the Excel file is opened, in order for the Stability and Control macros to work properly. Due to lack of resources, this module is not hooked up to automatically update parameters on the Performance page, yet it does work well enough to guide the user on fin sizing based on the geometry and inertias from the other modules.

A3.1.7 Division into User Areas and Calculation Areas

It is a feature of Excel that very little is hidden. All calculations with the exception of Macros are usually left visible on the spreadsheet. It can be challenging to organize a spreadsheet in a visually pleasing way once important macros have been created. As a result, the calculation areas of many spreadsheets can be somewhat cluttered.

This spreadsheet is organized into “user areas” and “calculation areas”. We have paid particular attention to organizing the user areas so that they are easily grasped and used. We have paid less attention visual refinement of the calculation areas.

Most cells have been colored based on the following guidelines. Cells intended for user input are colored bright yellow. Cells that are not as commonly changed are pale yellow. Other cells that receive input from another page in the tool are colored orange – do not manually enter numbers in the orange cells! Green cells are typically output cells in which the user may be interested.

A4 PERFORMANCE

A4.1 Performance Concept

This is the tool's primary page. All other pages are driven, in part, by the Performance page. Major inputs are made, key macros are run and key computations and results are presented on this page.

The short version of how to use this page: Select a preloaded airship to evaluate or modify, or select an empty column to create a new airship. Modify or enter the desired requirements and characteristics. Click on the "Converge Weight", "Converge HP" or "Converge Length" buttons to size the airship as desired. Examine the resulting airship characteristics. It is a feature of this page that inputs are modified by the sizing process so inputs may also be outputs depending on which sizing button is clicked. That's the short version. The long version follows.

The page is divided into major blocks with different functions. The left hand columns from B and C remain visible at all times. This column includes the Airship and Mission Selector block and a display of key values for the selected airship. Columns E through AK are provided for inputs of alternative airship designs, one column per design. Columns AN through AQ display geometric and mission results for the selected airship and contain buttons that launch sizing macros. Columns AR through CC perform a stepwise computation of airship performance for the sizing mission. Columns CT through DJ perform a stepwise computation of airship performance for the reference mission. To be clear, the "sizing mission" is used to size the airship characteristics. The "reference mission" is an alternative mission in which the previously-sized airship is flown without changing its characteristics. These major blocks are described in greater detail below.

A4.1.1 Airship and Mission Selector

In the upper left corner of the page in Cells A1:C4 are important control buttons as shown in Figure A- 2.

Figure A- 2. Airship and Mission Selector Buttons

The five buttons are described below.

Sizing Mission. Clicking the upper left button, "Mission 1", slides the right hand portion of the page to the left so the sizing mission results are visible. These results are presented for the selected airship. When the selected airship is changed the results also change. Results may not be converged unless the desired sizing buttons have been clicked.

Reference Mission. Clicking the "Mission 2" slides the right hand portion of the page even farther to the left so the reference mission results are visible. These results are also responsive to the selected airship.

Home Button. The home button (guess which one this is!) returns the screen to the top left corner of the page.

Airship Selector Buttons. The green right and left arrows move the selected airship right and left in the range of Columns E though AH. One click of either button moves the selected one column to the right or left. Holding down the button does not move multiple columns. The user should wait until the computation is down following each individual click before clicking another time. Selecting a particular airship loads the inputs for this airship into the other pages and into the mission performance section of the Performance page. The selected, or active, airship is indicated in two ways. The number in red Cell C3 corresponds to the number of the selected airship in Row 1. Also, the selected airship name in Rows 4 and 5 changes from green (inactive) to a highlighted blue-white scheme. Figure A- 3 shows both the red cell with the selected airship, the airship number in Row 1 and the highlighted selected airship, the GZ-20A.

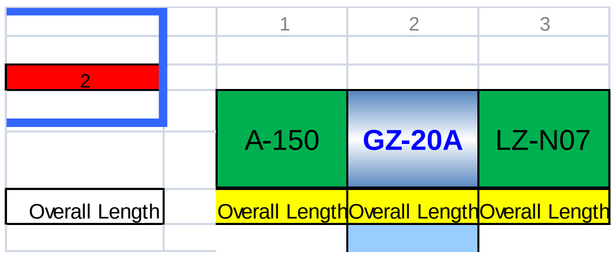


Figure A- 3. Indication of Selected Airship

Red Number. The number in the red cell in this block is the reference number for the airship. This number is used internally by the spreadsheet mechanism and <u>is not a user input</u>. The cell is colored red because an input in this cell will damage the sheet.

A4.1.2 Key Airship Results

The blocks in Columns B and C report key characteristics of the selected airship. These characteristics are simply transferred from the selected airship column. As a result, the characteristics are a mix of inputs and outputs.

A4.1.3 Airship Inputs

This section describes the concept of the airship inputs. A detailed explanation of each input is provided in Section A4.2.

The concept is that inputs for the selected airship are made in the airship's highlighted column. For example, if the second airship column is selected (the GZ-20A in Figure A- 3) then inputs must be made in that column, not in Column C! A value may be entered in each cell. This value may be in the form of a number or an equation or a selection from a pull-down menu. In some cases, equations are simpler to enter than a number – it's up to the user to decide.

The three different sizing buttons (weight, HP or length) attempt to converge the design by manipulating different sets of values in this column. The values modified by each button are shown in Table A- 1. A full convergence can be reached by clicking both the HP and Length buttons. When big changes are made in the inputs it may be necessary to click through the converge buttons more than once. If an airship does not close and keeps growing in size, it is most likely a flawed design. An example of this is a very long thin airship with a large concentrated payload. As the airship grows in volume to lift the weight, the bending moment on the structure grows faster than it can converge.

Table A- 1. Values Adjusted by Each Converge Button

Converge	TOGW Seed	Empty Weight	Max Fuel Wgt	HP per Engine	Overall Length	Gas Volume
Weight	Yes	Yes	Yes	No	No	No
HP	Yes	Yes	Yes	Yes	No	No
Length	Yes	Yes	Yes	No	Yes	Yes

A4.1.4 Results Summary

Columns AN through AQ provide a summary of results and contain the Converge buttons described above in Section A4.1.3.

A wire frame illustration of the airship is provided near the top of this block. This can be used to confirm that the correct airship is selected and that its geometric inputs are coherent. Front, side and isometric views can be selected by clicking the buttons up to the right from the illustration. An example illustration of the GZ-20A airship is shown in Figure A- 4.

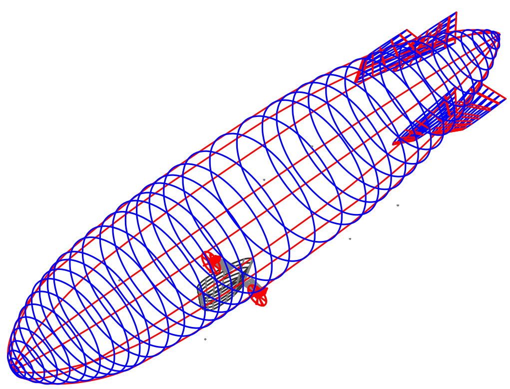


Figure A- 4. Example Isometric Illustration of the GZ-20A Airship

An altitude-distance plot of the sizing and reference mission is provided. This can be used to check for errors in the mission specification and to obtain a visual concept of the mission profile. An example mission for the GZ-20A airship is shown in Figure A- 5. Note that the reserve portion of the sizing mission is included in the profile.

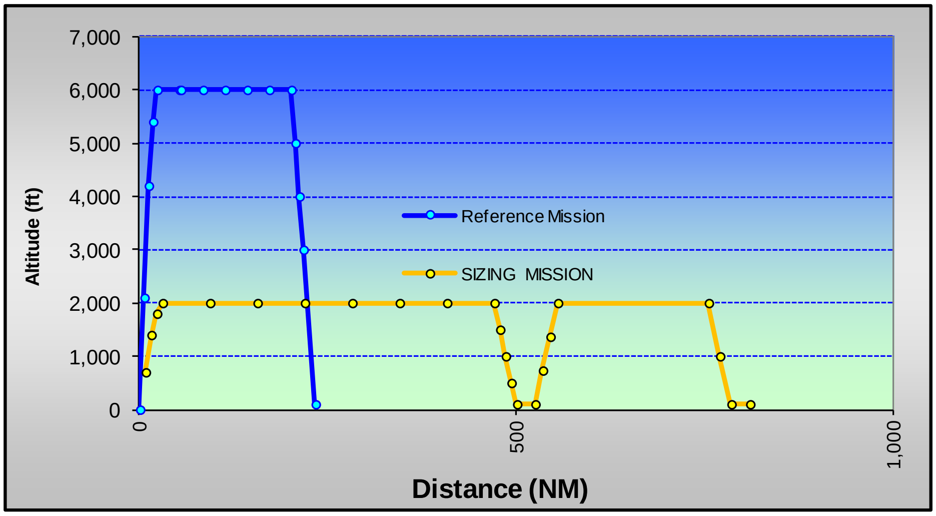
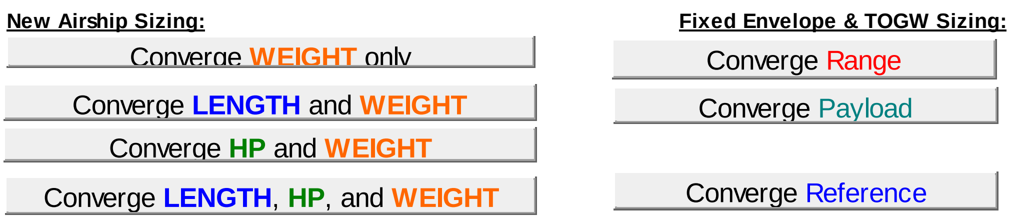


Figure A- 5. Sizing and Reference Mission Profile for GZ-20A Airship

A summary of sizing mission and reference mission results are shown in a data block below the mission profile. An example of this block is shown in Figure A- 6 for the GZ-20A. This figure also shows the location of the three Converge buttons.



	Mission 1 (Sizing)	Mission 2 (Reference)
Takeoff Weight, Error: 2,219.0	696,642	703,738
Range, NM	2,800	2,520
Cruise Drag, lbs	15,308	24,647
Fuel Burn + Reserves, lbs	54,314	63,819
Payload, lbs	170,000	170,000

Figure A- 6. Summary Mission Results and Converge Buttons

At the bottom of this section is a plot that shows the airship hull's lift coefficient versus the distance along the sizing mission. This plot corresponds to the Mission Profile plot shown in Figure A- 5. This plot assists the user in fine-tuning the airship's initial buoyancy factor (static lift/MTOGW) and the effect of fuel consumption over the mission distance. An example is shown for the GZ-20A in Figure A- 7.

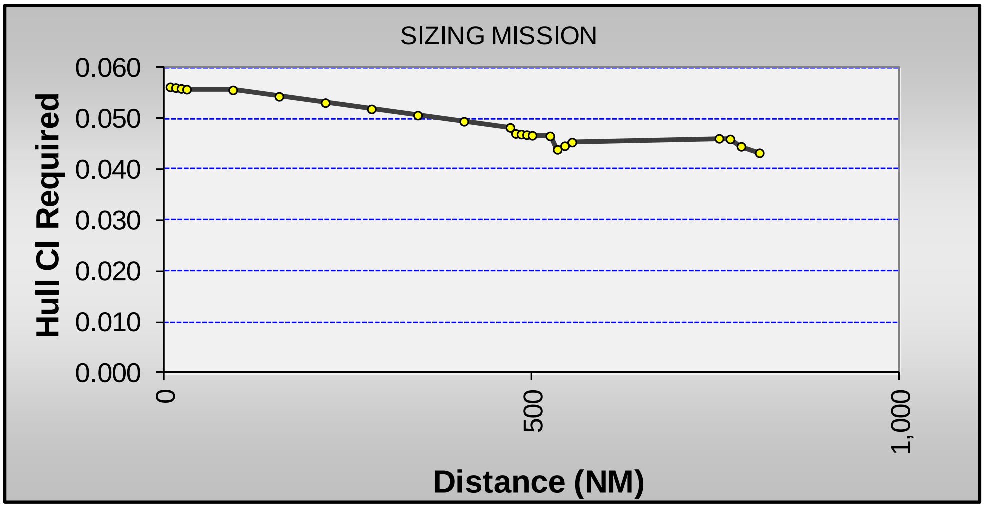


Figure A- 7. Hull Lift Coefficient versus Mission Distance for the GZ-20A Airship.

A4.1.5 Airship Performance – Sizing Mission

Key concepts of the sizing mission are described in this section.

When the airplane is sized for using the Converge buttons, it is sized for the sizing mission. In contrast, when the airship flies the reference mission the airship's physical characteristics such as empty weight, size and power remain fixed.

The sizing mission computations can be moved into view by clicking on the Mission 1 button in the "Airship and Mission Selector" block as described in Section A4.1.1. At the left edge, under the heading "Sizing Mission", are the descriptions of the quantities developed to the right.

The sizing mission is divided into eight flight segments. These are:

- Climb to operating altitude
- Cruise
- Descent
- Loiter
- Reserve climb
- Reserve cruise
- Reserve descent
- Reserve hold

Most of the flight segments are divided into smaller segments. Successive estimates of performance are made for each segment. Each following segment starts with a different weight to account for fuel burned in the prior segment as well as possibly different air density, temperature, gravity and other factors.

A4.1.6 Airship Performance – Reference Mission.

The reference mission computations are moved into view by clicking the Mission 2 button as described in Section A4.1.1. Descriptions of each quantity is located under the heading "Reference Mission".

The reference mission is divided into 3 flight segments:

- Climb to ICA
- Cruise
- Descent

As for the sizing mission, flight segments of the reference mission are also divided into smaller segments for increased precision.

A4.2 Airship Performance Inputs

As described in Section A4.1.3, inputs are made in the selected airship's column (not in Column C!). Specific inputs are described in some detail below. Note that the selected airship's column can be brought into view with the page's scroll bar in the lower right hand corner. This moves the airship inputs without moving the description and active value in Columns B and C. The inputs are grouped according to category as listed below.

- Sizing Mission Requirements
- Reference Mission Requirements
- Geometry
- High-Level Weights
- Propulsion (General)
- Configuration
- Detailed Mission Requirements
- Miscellaneous Inputs
- Aero Loads Inputs, Sizing Case 1
- Internal Combustion Engine
- High Level Weights
- Cargo Bay
- Air Cushion Landing System
- Outputs

A5 VEHICLE GEOMETRY

This section describes how geometry is formed in this tool. The previous section, Section A4, describes how the main page of the tool, "Performance", is operated. To avoid confusion, it is important to note that some of the geometry definition occurs within the Performance page - this is described in this section.

This section combines instruction for four of the tool's pages: Performance, Geometry1, Geometry2 and Layout. These are combined because of the overlapping nature of the concepts employed. General geometry concepts are first described. This is followed by specific instructions for the four tool pages.

A5.1 Vehicle Geometry Concept

A5.1.1 Coordinate System

A left-handed coordinate system is used. The origin is the tip of the airship nose. The X-axis extends aft; the Y-axis extends to the airship's port side; the Z-axis extends upwards. Coordinate dimensions are in feet. Variable inputs for length are in feet; area is in ft^2; volume in ft^3.

A5.1.2 View

A large wireframe image of the entire airship is provided at the upper left corner of the Layout page. The viewing angle may be selected by the user by clicking the macro buttons near the upper right corner of the image. Four standard views are provided: Top, Side, Front and Isometric as shown in Figure A- 8.

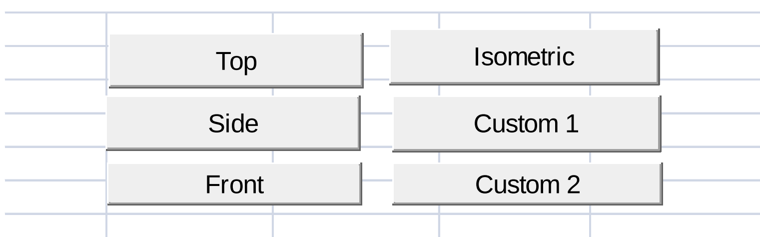


Figure A- 8. Standard and Custom View Buttons

		Custom Views	
		1	2
	Azimuth	60	45
	Elevation	30	10

Figure A- 9. Custom View Inputs

Two custom views are also provided. The custom angles are controlled in the yellow input cells over to the right from the view buttons as shown in Figure A- 9. This allows the user to see the vehicle from any angle.

The concept of these views is that the airship is fixed in space and the viewpoint moves around. The azimuth angle is the heading of the view where a nose-on view has a zero azimuth angle and a positive angle is to the vehicle's left. The elevation angle describes the angle at which the viewpoint is above the X-Y plane – a positive elevation views the airship from above this plane. The four standard view buttons automatically enter the azimuth and elevation for those views. These four views are illustrated in Figure A- 10.

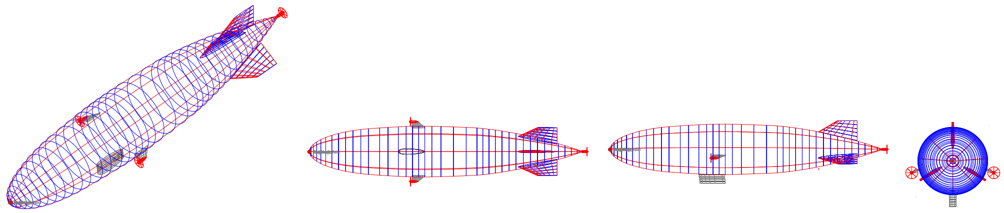


Figure A- 10. Example View Options: Isometric, Top, Side and Front

In addition to the wireframe vehicle image, it is also possible to display point masses and component names. This option is selected by a checkbox labeled "Display Misc Masses?" above the component list.

The view does not include perspective scaling – near and far elements are the same size. This, in combination with the wireframe depiction, can result in an effect that makes the far components (tails for instance) appear larger than they are. This effect can be countered with a little visual gymnastics involving dueling perceptions. For example, in the isometric view the conventional interpretation is that the vehicle is viewed from above, with the nose close to the viewer. With some effort, it is also possible to see the vehicle from below, with the nose away from the viewer. The odd thing is that the tail in the first view will look larger than the tail in the second view.

A5.1.3 Symmetry

The vehicle is assumed to be laterally symmetric. That is, it is symmetric about the X-Z plane. This assumption is reflected in the inputs and the computations.

A5.1.4 Archive

The tool contains an archive of historical and user-generated airship designs. Historical and prior user-generated designs can be used to calibrate new designs in terms of geometry, weight and performance. They can also be used as a starting point for a new design.

User generated designs can be archived for later recall.

A5.1.5 Concept of Vehicle Geometry Inputs

Vehicle geometry inputs are made in four pages: Performance, Layout, Geometry 1 and Geometry 2.

- The Performance page displays characteristics of 30 different airships in columns. One of these is selected to be "active" and its characteristics are loaded into the other geometry input pages. This may serve as a starting point for a new airship.
- Layout is used to define engine, fin and gondola geometry.
- Geometry 1 defines the size and shape of single-lobe envelopes.
- Geometry 2 defines multi-lobe envelopes.

The general process of defining a new airship's geometry follows these basic steps:

- Select "seed" geometry from the 30 options on the Performance page. This seed is preferably similar in configuration to the desired new geometry.
- Adjust the shape of the seed envelope in Geometry 1 or Geometry 2, depending on the number of envelope lobes.
- Redefine the seed's engine, fin and gondola geometry on the Layout page.
- The software automatically archives the changes to the last configuration before moving on to the next in the lower region of the Layout page. Until the user is fully familiar with how the archival system works, it is advised not to make changes to this region.
- Once geometry is defined, weights and propulsion characteristics can be defined.
- Vehicle sizing and vehicle performance can then be completed – this is the object of the spreadsheet.

A5.2 Geometry on "Performance" Page

The concept of how geometry is entered on the Performance page is challenging to grasp and is explained in greater detail in Section A4.1.3. What makes it challenging is that depending on what the user is doing, it may be that geometry is entered on the page or it may be a result of several different sizing routines (with different constraints). That said, the basic idea is that key geometric inputs such as length or diameter may be made on the page as a way to get started or as the final dimensions. These inputs may also be made on the various geometry pages described below.

A5.3 Geometry on "Geometry 1" Page

A5.3.1 Geometry1 Concept

The "Geometry 1" page is used to define the geometry of single lobe airship envelopes. Geometry is defined parametrically to enable rapid changes of major variables such as length and diameter without changing the general form of the envelope. This geometry is automatically exported to the Vehicle Layout page for completion of gondola, fin and propulsion system geometry.

The envelope is assumed to be laterally symmetric. This reduces the number of inputs required by half.

The envelope geometry is defined by its maximum half-breadth outline and a series of cross sections strung on this outline. The cross sections are defined in four quadrants by their height, width and rho-value. It is assumed in "Geometry 1" that the centerline junctions between the left and right quadrants are slope-continuous. That is, there can be no chine along the centerline. In contrast, the junction at the junction between the upper and lower quadrants can be controlled to provide a chine or concave crease.

Despite the simple data entry format, precise geometry is created. The envelope form can be exported in VRML and CATIA format for use in programs external to the tool.

A5.3.2 Geometry1 Background

A5.3.3 Rho-Value Conic Curves

A conic section is a planar section through a cone. It may be an ellipse, parabola or hyperbola depending on its "rho" value. Ellipses are formed with a rho of less than 0.5; parabolas have a rho of exactly 0.5; hyperbolas have a rho of greater than 0.5. A circle can be formed with a "square" ellipse with a rho value of the square root of two minus 1 = ~0.4142.

A rho value conic may be defined by a starting point, an end point, a corner point and a rho value. The conic starts at the starting point in a direction tangent to a line from the start point to the corner. It ends at the end point tangent to the corner point – end point line. Its curvature is defined by the "rho" value. A rho value near zero places the curve's control point near the midpoint of a line between the start and end points. A rho value of 0.5 places the control point in the middle; a value near 1.0 forms a nearly sharp corner. Three examples are shown in Figure A-11. From left to right, these have rho values of 0.1, 0.5 and 0.9. The start point, end point and corner point may be selected arbitrarily – they need not be orthogonal as shown here.

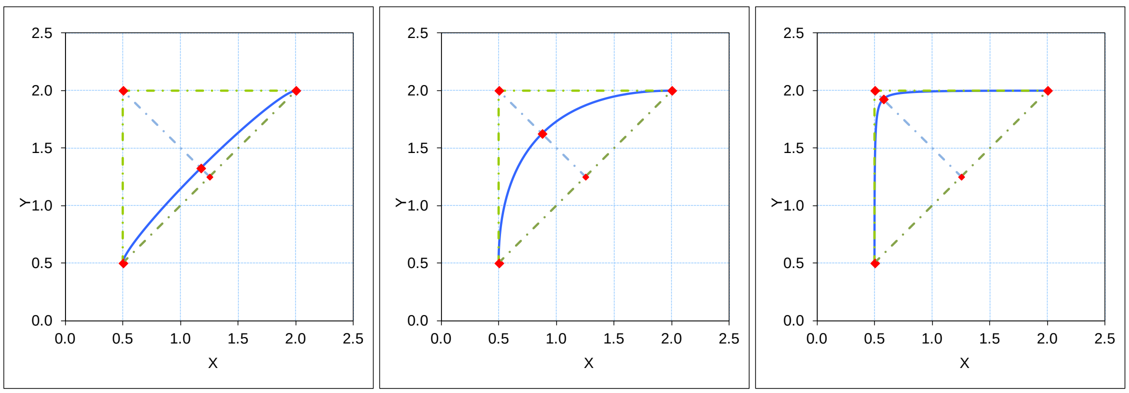


Figure A- 11. Example Rho-Value Conic Sections with Rho = 0.1, 0.5 and 0.9

Figure A- 12 illustrates a quarter circle formed as a "square" conic section with a rho value of 0.4142. "Square" in this context means that start point and end point are equidistant from the corner point and the two lines formed by the three points are at right angles.

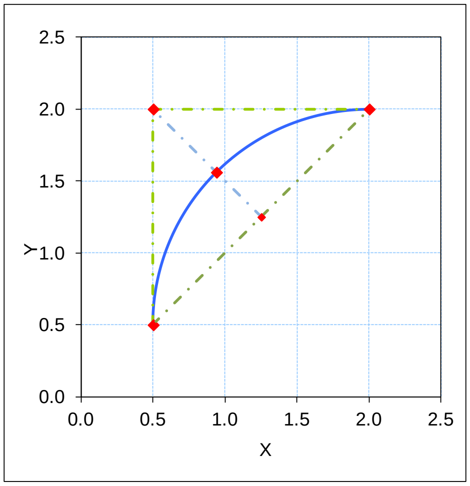


Figure A- 12. Example Quarter Circle Formed by Rho-Value Conic

Maximum Half-Breadth Curve

A "maximum half-breadth curve" (MHB) is the curve that follows the point of greatest width of a fuselage or hull from nose to tail. At each lengthwise station, the cross section has a point of greatest distance from the central plane (X-Z plane). The curve that passes through these points is the MHB. This curve is not necessarily planar.

A5.3.4 Geometry1 Inputs

Envelope Top View Shape

A parametric top view projection of the MHB outline is specified by three linked rho-value conics. These curves nominally fit within a box one unit high by one unit wide as illustrated in the "Top View" plot at the top left of the page. An example outline is shown in Figure A- 13; inputs for this shape are shown in Table A- 2. The units of width and length are multiplied by the tool to create an airship with the overall dimensions specified later in this section. Joints between the three MHB outline segments in Figure A- 13 are denoted by the small yellow circles. In this example, there is a nose section, constant section and tail section.

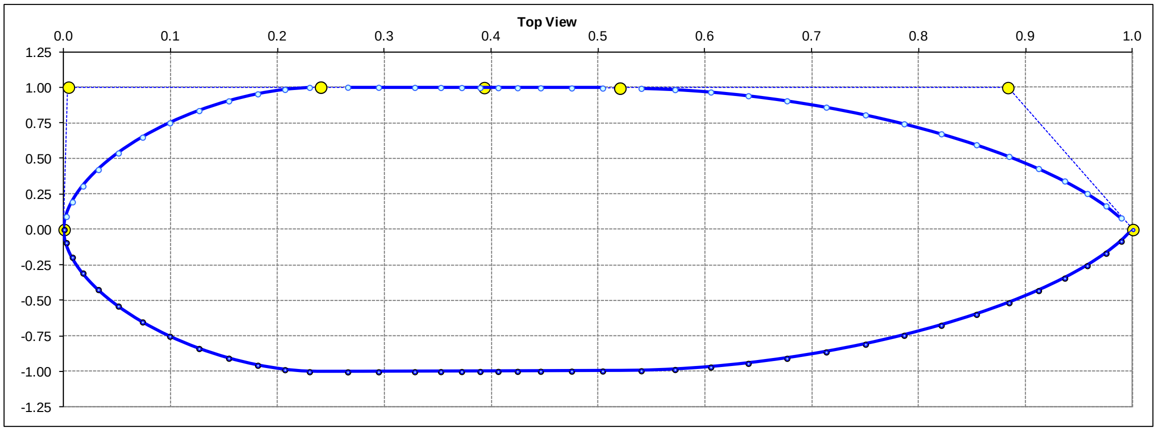


Figure A- 13. Top View MHB Outline

Table A- 2. Control Point Inputs for Top View MHB Outline

	Top View Control Points	
	x	y
start point	0	0.00
corner point	0.004	1.00
end point	0.2400	1.00
Rho	0.35	0.538
start point	0.24	1.00
corner point	0.393	1.00
end point	0.52	1.00
Rho	0.7	2.333
start point	0.52	1.00
corner point	0.883	1.00
end point	1.00	0.00
Rho	0.4	0.667

The three conics are strung nose-to-tail; the end point of the first conic is the start point of the second conic. The start point of the last conic is specified – this is the end point for the middle conic. The control points for the three conics are defined in the input box labeled "Top View Control Points" to the right of the top view plot as illustrated in Table A- 2. A wide range of shapes can be precisely defined with the three curves. Key points include:

- Typically, the first start point is located at (0,0); the end point at (1,0)
- The length of the envelope (typically 1.000) is multiplied by the overall length. If the envelope is longer than 1.000 the resulting airship will be longer than the specified overall length.
- The maximum width of the envelope (typically 1.000) will be multiplied by the "maximum vertical diameter" divided by two. Again, if a maximum value other than 1.000 is reached by the envelope, the dimension will not match.
- The location of the first corner point controls the slope at the nose. In Figure A- 13, the first corner point is at an X-value of 0.004, so the nose is slightly pointed.
- If the envelope is to have a constant section (a region of constant width) with a smooth transition from the nose to the constant section, the Y-value of the first corner point and the end point should be 1.000.
- A rho-value conic forms a line if the three control points are collinear. For example, the constant section in Figure A- 13 is formed by using the same Y-value of 1.000.
- The points above also apply to the aft section conic: The corner point controls the slope at the tail; smooth transition from a constant section is achieved by using a Y-value of 1.000 for the start and corner points.

An additional example top view outline is provided in Figure A- 14 with accompanying inputs in Table A- 3.

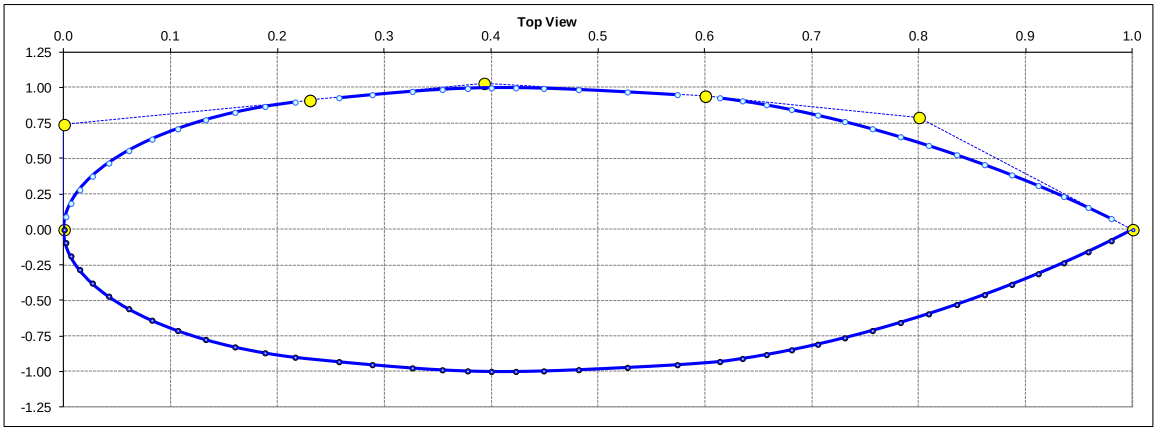


Figure A- 14. Additional Top View MHB Outline

Table A- 3. Control Points for Additional Top View MHB Outline

	Top View Control Points	
	x	y
start point	0	0.00
corner point	0	0.74
end point	0.2300	0.91
Rho	0.43	0.754
start point	0.23	0.91
corner point	0.393	1.03
end point	0.60	0.94
Rho	0.7	2.333
start point	0.60	0.94
corner point	0.8	0.79
end point	1.00	0.00
Rho	0.45	0.818

Additional points are illuminated by Figure A- 14:

- There is no guarantee of slope continuity at the transition between the three curves. This is achieved only when the line connecting the first corner point and endpoint is collinear with a line connecting the next start point and corner point. This is not automated in this version of the tool.
- If the constant section is not constant, as in this example, the width of the envelope will be less than the width defined by the corner point. It is desirable to reach a value close to one. This can be achieved by clicking and holding on the envelope's widest point (light blue circles). Excel will provide the coordinates of that point. The needed increment to reach one, for example 0.02, can be added to the Y-value of the corner point. This will drag the envelope curve out very close to 1.00. This should be sufficiently accurate considering the approximate nature of the tool.
- Variations in rho value have a powerful influence on the envelope wetted area, volume and center of volume. These are reported in a purple block below the Top View.

Overall Dimensions

Two overall dimensions of the envelope are specified at the top of this page:

- Overall length, in feet
- Maximum vertical diameter, in feet.

These two entries do not strictly define the envelope dimensions. More precisely, the inputs are multiplied by the dimensions of the envelope top view shape which may not be precisely one in length or width.

The effect on overall length and diameter on envelope shape is illustrated in Figure A- 15. This shows three envelopes with an overall length of 246 feet based on the MHB shape from Figure A- 14 with circular cross sections. From left to right the diameters are 46, 23 and 92 ft. All other geometric inputs are the same.

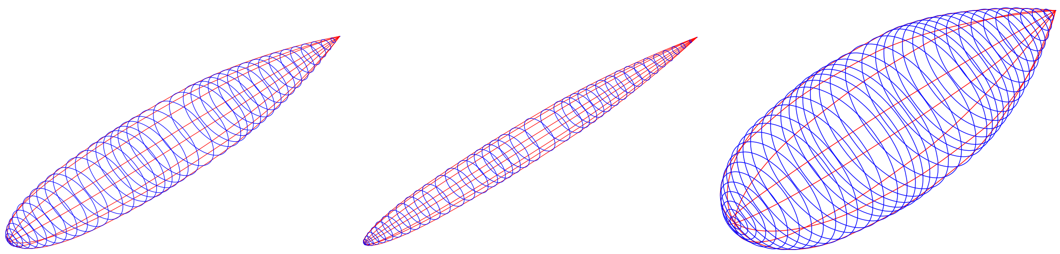


Figure A- 15. Envelopes with Common Inputs but Different Length to Diameter Ratios

Envelope Cross Sections

As noted above, the envelope is assumed to be laterally symmetric – only one side is defined.

The cross section shapes and their vertical location are defined in a large data entry block below the "Top View Control Points" block. This block is six columns wide by 41 rows long. The six columns define characteristics of the cross section; the rows pertain to the longitudinal station of each section. The section stations are located at the calculated points along the three conics forming the MHB. These points are tied to the so-called "u" value of the conic used in the computation of the conic. The resulting X-values of these points vary with the control points and the rho value and are unlikely to be evenly spaced. On the other hand, the points tend to be more tightly spaced in areas of sharper curvature, providing a more accurate visual representation. These points are designated in the Top View as small light blue circles. It is possible to use spacing section as an indication of local curvature: widely spaced sections indicate a region with low curvature and vice-versa.

Many envelope designs may share the same input value through much or all of the input columns. Input speed can be increased by entering the values across the top row and then "filling down" using the standard Excel process.

The six cross section characteristics are:

- Upper Rho

This is the rho value of the upper quadrant. If the section width and height are equal, a rho value of ~0.4142 yields a quarter-circle. Refer to Section A5.3.3 for more information about rho values.

- Lower Rho

This is rho value of the lower quadrant.

- Upper Corner Point Y

This value controls the lateral location of the upper quadrant corner point, where a value of 1.000 places the point directly above the section's end point at the MHB (assuming the MHB is located at 1.000 – see "Width Fraction of Height" below). A value less than one places the corner point inboard of the MHB. This results in a sharp chine at the MHB (unless the lower quadrant is lined up with this angle). A value greater than one can be used. This widens the upper quadrant beyond the MHB and results in a concave crease at the MHB (unless the lower quadrant is lined up with this angle). These variations are illustrated in Figure A- 16, where the green dot in the upper right corner is the corner point.

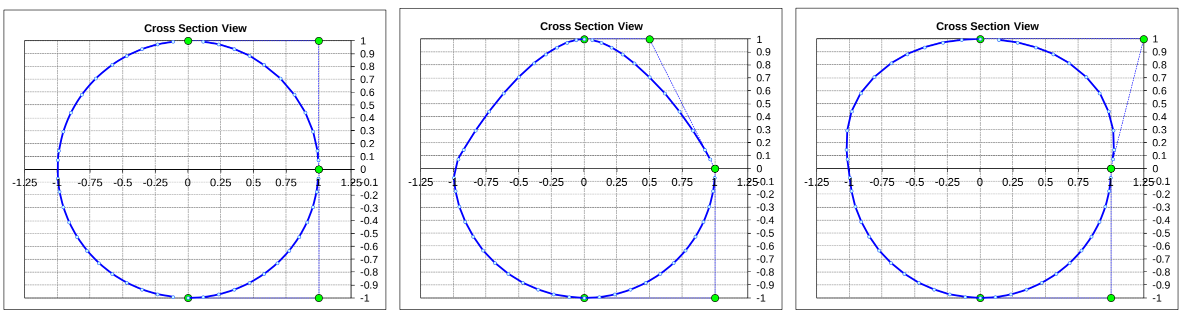


Figure A- 16. Cross Sections with Upper Corner Point Y-Values of 1.00, 0.50 and 1.25.

- Lower Corner Point Y

The variable is the same as the upper corner point input except that it controls the lower portion of the cross section. Three examples are shown in Figure A- 17. The first example shows a section with both upper and lower Y-values set to 0.50. This produces a sharp chine at the MHB. The second sets both values to 1.25; this produces a concave crease at the MHB. The last sets the upper value to 1.25 and the lower to 0.75. This results in slope continuity at the MHB. Note that the last two examples result in an envelope that is wider than the controlling MHB curve. This is a kind of oxymoron but is a minor infraction in the scheme of things.

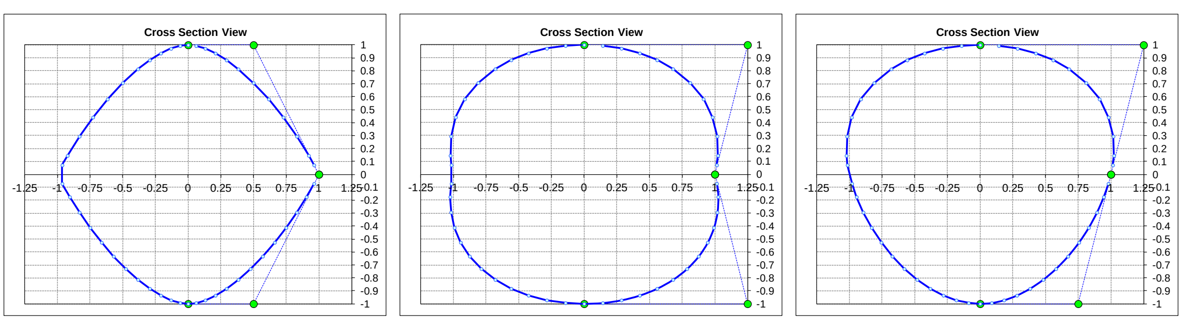


Figure A- 17. Cross Sections with Lower Corner Point Y-Values of 0.50, 1.25 and 0.75.

Figure A- 18 shows an isometric view of the envelope using the cross section from the first example in Figure A- 17 throughout the length of the airship.

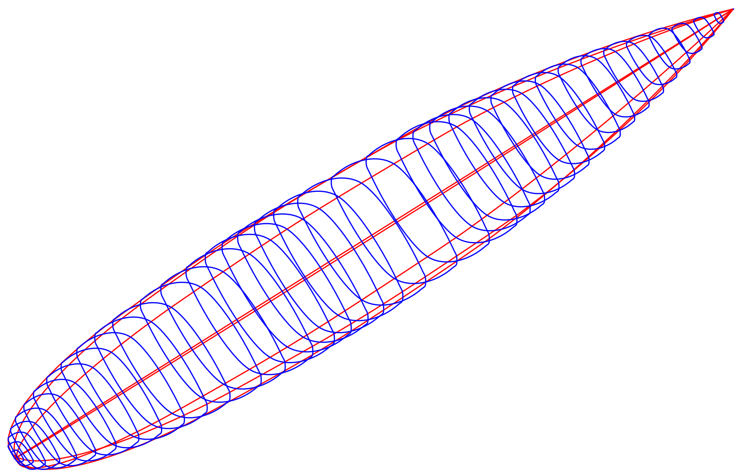


Figure A- 18. Isometric of Envelope with Upper and Lower Corner Points Set at Y = 0.50

- Width Fraction of Height

This input defines the lateral location of the control point at the MHB for both the upper and lower portions of the cross section. This input does not affect the location of the corner points. Three examples are shown in Figure A- 19. It is important to note that this input controls the final width of the envelope – the height is unchanged but the width is altered. Note that the MHB line defined in the top view is not definitive – in the final envelope shape the top view MHB is multiplied by the width/height ratio at each station. This input affects the envelope's computed wetted area, total volume and center of volume. In the first example in Figure A- 19, the width/height ratio is set to 0.50. This pinches in the MHB line and cuts the width of the airship at this station in half. In the second example, the width/height ratio is increased to 1.25. This widens the MHB and creates a chine at the MHB. In the last example, the ratio is set at 1.25 and the corner points are also moved out to 1.25. This results in an elliptical cross section.

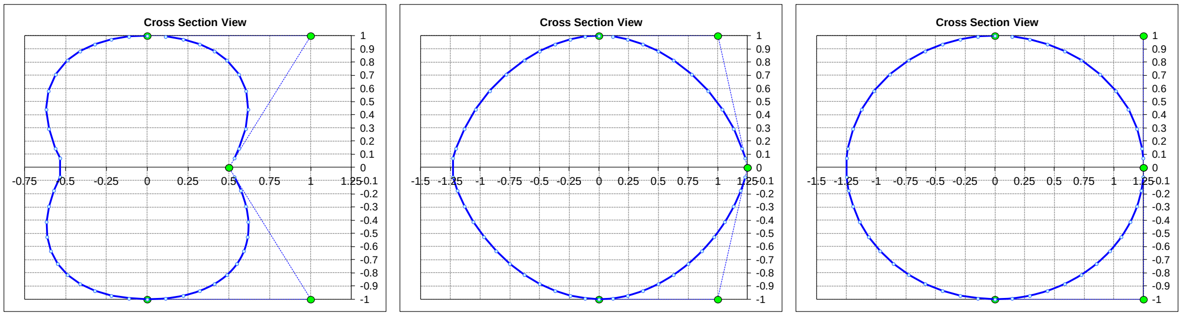


Figure A- 19. Effect of "Width Fraction of Height" Input.

Figure A- 20 illustrates how changing the width/height ratio affects the final MHB line. Here, several of the mid-body cross sections have width/height ratios set to 0.50 without changing other values.

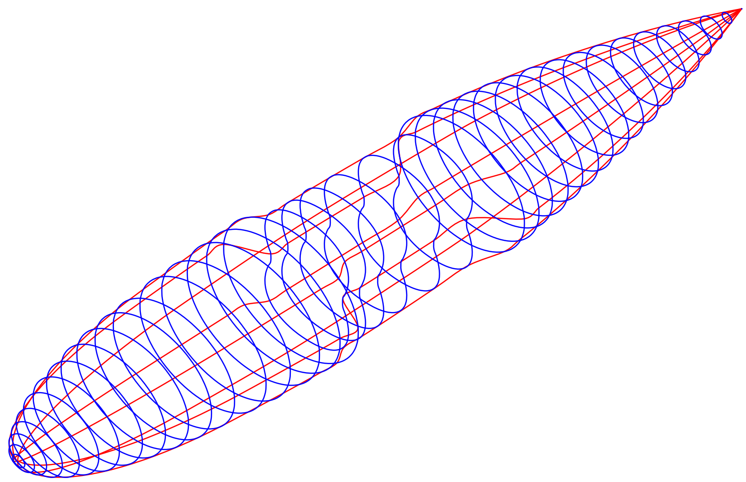


Figure A- 20. Isometric of Envelope with Central Sections Width/Height Ratio Set to 0.50

- Midpoint Height

This input defines the vertical location of the cross section's MHB point. This provides an additional degree of freedom in shaping the envelope. A positive value moves the MHB upwards; a negative value moves it down; zero is the "neutral" value. The input value must be greater than or equal to -1.00 and less than or equal to 1.00. Values outside this range cannot form a closed envelope and simply don't work in this tool. Values of -1.00 and +1.00 result in a sharp corner. Figure A- 21 provides two examples – the first with the midpoint raised to 0.50; the second midpoint is lowered to -0.50.

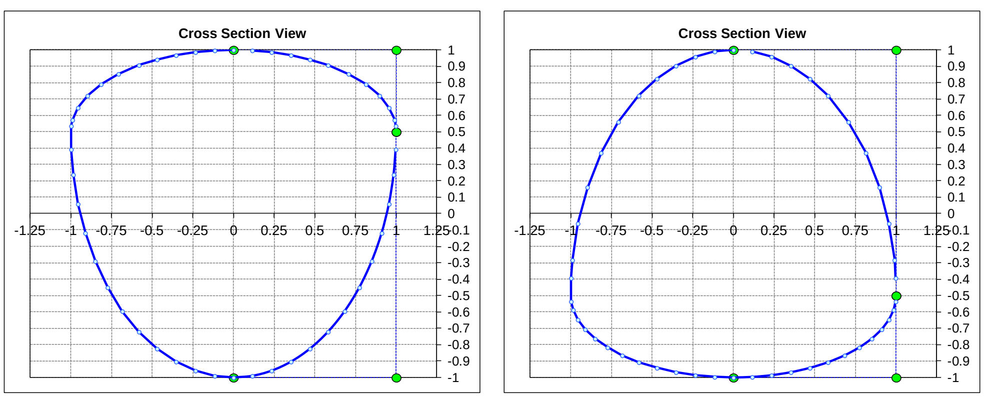


Figure A- 21. Example Cross Sections with Raised and Lowered Midpoint Height

Figure A- 22 shows an entire envelope with the second cross section in Figure A- 21. Note that this option retains slope continuity at the MHB line unless the value is set to +1.00 or -1.00.

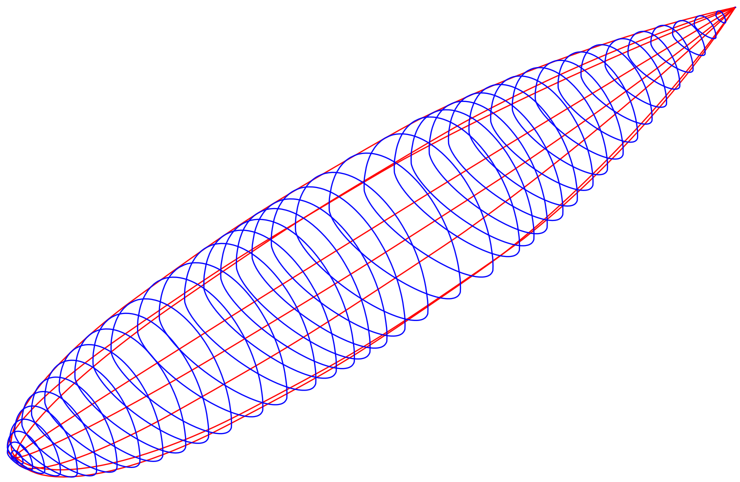


Figure A- 22. Envelope with Midpoint Height Lowered to -0.50

Several observations on this section may be helpful:

- These six inputs may be combined simultaneously to achieve a wide range of shapes.
- Envelope characteristics including wetted area, volume and center of volume are determined by the surface formed by the sections. Changes to any cross section result in changes to these characteristics.
- There is presently no mechanism to change the centerline camber of the envelope. The side view outline of the airship is identical to the top view of the MHB as specified in the "Top View" plot. This top view is assumed to be symmetrical, so the side view at the centerline is also symmetrical. Some effective camber may be achieved with the Midpoint Height input as well as with the upper and lower rho and corner point inputs. Outputs

Plots

Several plots are provided on the Geometry 1 page. These provide immediate feedback to the designer for at least two reasons. First, it permits "eyeball" adjustment of inputs to reach desired characteristics or appearance. Second, it quickly reveals input errors – these tend to be obvious in one or more of the plots.

Plots included are described below.

- Top View

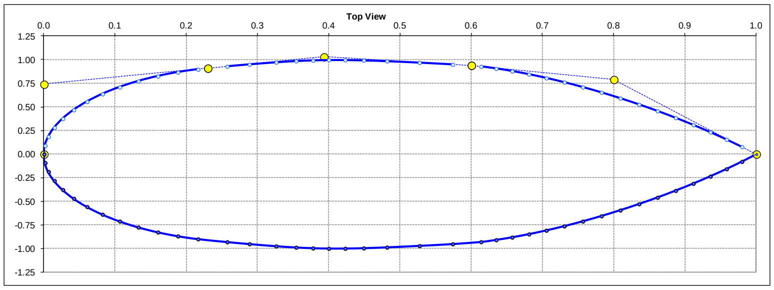


Figure A- 23. Top View Plot of MHB

This two-dimension plot shows the projected top view of the envelope maximum half-breadth curve as defined by the Top View Control Points as described in Section A5.3.4. The MHB curve is shown in deep blue; control points for the three conics that make up the MHB are shown as yellow dots; computed nodes of the conics are shown as small light blue dots.

This plot is the foundation on which the numerous cross sections are strung. The actual envelope maximum half-breadth line may be different from the one shown in this plot.

- Cross Section View

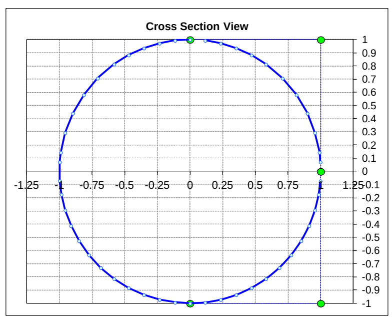


Figure A- 24. Cross Section View

This plot shows a single, selected cross section of the envelope taken parallel to the Y – Z plane. The cross section is selected by clicking the up-down arrows to the left of the cross section input block. The selected section row is indicated by a red highlight.

The selected cross section is shown in deep blue; control points are shown as bright green dots; computed nodes of the conics are shown as small light blue dots.

- Cross Section Inputs Plot

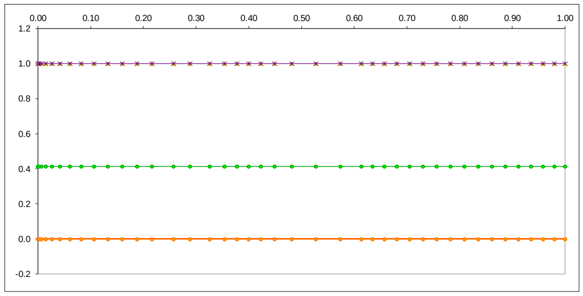


Figure A- 25. Cross Section Inputs Plot

The Cross Section Inputs plot graphically displays the values entered into the cross section input block. This permits rapid inspection and spotting of erroneous inputs. Each curve in this plot has a different color – this corresponds to the color of the bottom cell in each column of the input block. For example, the rho value for the upper portion of the section is color-coded bright green. Some of these curves may overlap.

- 3-D View of Envelope

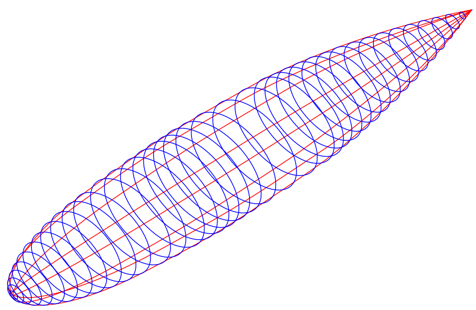


Figure A- 26. Three-Dimensional View of Bare Envelope

This three-dimensional view of the bare envelope may be viewed from different angles as selected by nearby macro buttons. This is described in Section A5.1.2. Angle input values for “Custom 1” and “Custom 2” permit user-selected view angles.

- 3-D View of Envelope with Components

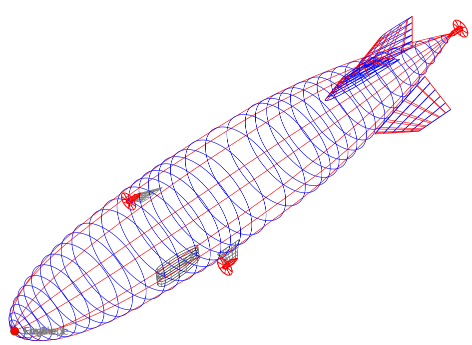


Figure A- 27. Three-Dimensional View of Envelope with Components

This is the same as the view of the bare envelope except that the components described on the “Vehicle Layout” page are included in their present state. This page is described in Section A4.

This page shares view control buttons with the bare envelope view. It is possible to display or hid the components names. This is controlled on the Vehicle Layout page as described in Section A4.

Key Characteristics

Key characteristics are included on this page to permit adjustment of the design and to identify significant errors in the input.

- Overall Length

This output may be compared with the "Overall Length" input to make sure that everything is working as expected. Errors may arise from a nose X value other than zero or a tail value other than one.

- Maximum Vertical Diameter

Maximum vertical diameter is determined by the width of the MHB curve in the Top View plot. Ideally, in this plot the MHB curve has a maximum value of one. If not, the output maximum vertical diameter will be different from the input maximum vertical diameter. Adjustment of the MHB control points can align these values.

- Wetted Area

Wetted area is the external surface area of the entire bare envelope – that which would be wet if it were underwater.

- Total Volume

Total volume is the internal volume of the bare envelope taken at its outer surface. This theoretical value does not account for internal components such as structure or unfilled volumes.

- Center of Volume X

This is the longitudinal location of the center of total volume as described above. This is analogous to center of gravity. The vertical and lateral centers of volume are not provided on this page.

VRML and CATIA

The final bare envelope form is defined by the stack of cross sections. These can be exported to Virtual Reality Modeling Language (VRML) tools or to the CATIA computer aided drafting program.

VRML shapes are represented by a series of 3D polygons represented in a text file. Each polygon has parameters that define its shape and appearance. When creating a VRML file, the bare envelope polygons are written to the output file longitudinally from the rear to the front. This process is then repeated radially until a half-envelope is complete. The exact process is repeated with opposite symmetry for the other side. Following the envelope, the fins and engines are output. Each polygon of the envelope is given a random shade of light blue. The fin polygons are given a random shade of red. The gondola, engine nacelles and propellers are grey. An example is illustrated in Figure A- 28.

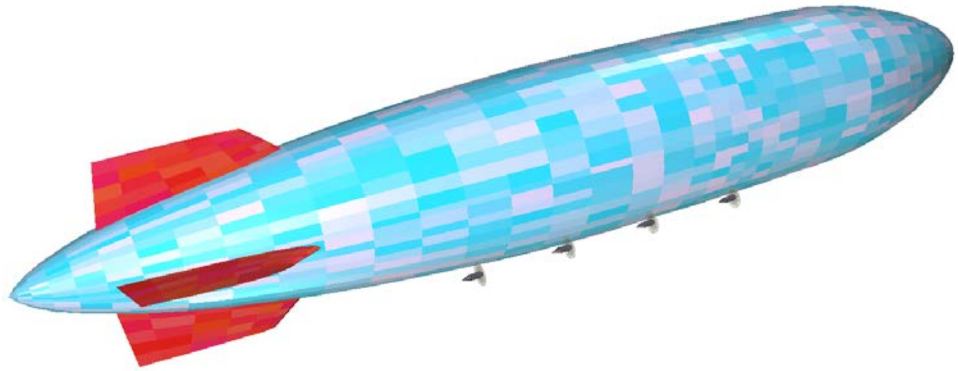


Figure A- 28. VRML Render of the USS Macon

The CATIA model is a parametric CAD model defined by the same inputs outlined in Section0. Only the bare envelope is exported, unlike the VRML output. There are two CATIA models, “LTA_Geometry1.CATPart” (for single-lobe designs) and “LTA_Geometry1.CATPart” (for multi-lobe designs). The single lobe model is currently limited to designs with a constant width/height ratio. An example of CATIA rendering of a tri-lobe envelope is presented in Figure A- 29.

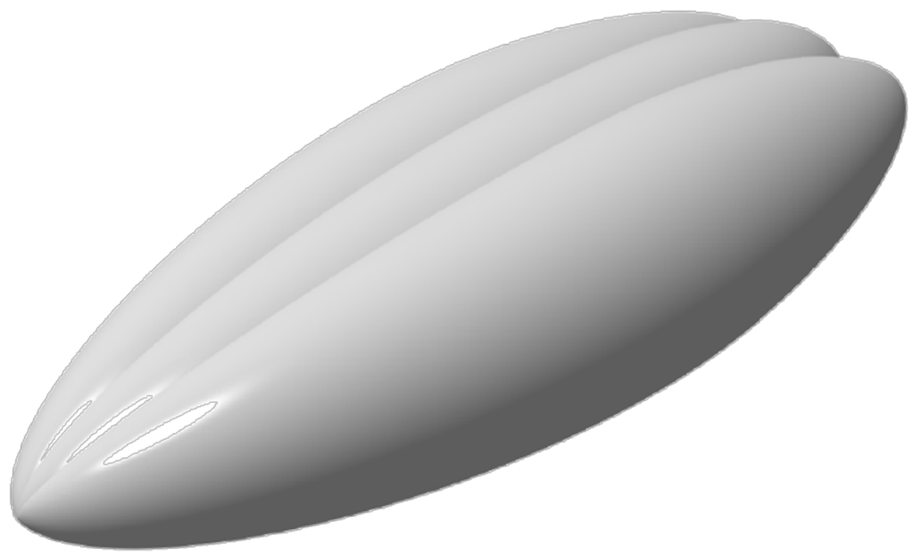


Figure A- 29. CATIA Render of Tri-lobe Envelope

Exporting geometry to CATIA consists of the following steps:

- Open the CATIA application and the relevant model (Geometry1 or Geometry 2)
- Open the LTA tool and navigate to either the Geometry1 or Geometry2 sheet.
- Press the “CATIA” button under the “Export Geometry” group.

If the user encounters a “User-defined type not defined” error they must navigate to the VBA window (Developer tab ->Visual Basic), open the references list (Tools -> References), and select the following references to CATIA:

- CATIA V5 GSMInterfaces Object Library

- CATIA V5 InfInterfaces Object Library
- CATIA V5 KnowledgeInterfaces Object Library
- CATIA V5 MecModInterfaces Object Library
- CATIA V5 PartInterfaces Object Library

A5.4 Geometry on the "Geometry 2" Page

A5.4.1 Geometry2 Concept

The page "Geometry 2" is used to define multiple-lobe airship envelopes. Multiple-lobe envelopes may provide a shape that is generally wider than deep. This may reduce induced drag for hybrid airships that rely on a combination of buoyancy and aerodynamic lift to fly. This page can generate envelopes with one, two, three or four lobes, but single-lobe envelopes are probably more easily defined using the Geometry 1 page.

Several geometric assumptions are made:

- Lateral symmetry – only two lobes are defined for a total of four lobes
- Each lobe has only circular cross sections as taken parallel to the Y-Z plane
- Each lobe is equally pressurized – the membrane linking lobes is straight at each station

These assumptions may not work perfectly in a detailed design. There may be a tendency for a real envelope, when pressurized, to deform slightly from the defined geometry. The imperfection is that an angled lobe with circular cross sections taken in the Y-Z plane may have non-circular cross sections taken in a cut perpendicular to the surface.

One may think of this page as being used to "construct" the envelope. The general idea is that each lobe is defined independently in terms of length, diameter versus length, centerline curvature as seen in the top view and camber as seen in the side view. The three lobes are then intersected by the tool which then fits a membrane between the intersecting surfaces. The designer must take some care to insure that the intersections are concave if the intention is to have connecting membranes operate in tension.

The lobes are numbered. Lobe 1 is the center lobe. Lobe 2 is an outboard lobe.

A5.4.2 Geometry2 Inputs

Non-Dimensional Lobe Inputs

Lobe 1 and Lobe 2 are independently specified by three sets of non-dimensional inputs. These are scaled to the actual envelope size by multiplying the length dimension by the envelope overall length; radii, lateral offset and vertical offset are multiplied by the reference half span. Overall length and reference half span are described later in this section. The inputs are:

- Lobe centerline Y value

The lateral location of each lobe's centerline is independently specified by two rho-value conics. These two conics are strung nose-to-tail to form a single curve. These two curves are plotted in the plot titled "Non-dimensional Lobe Centerlines – Y" as shown in Figure A- 30. These curves are manipulated by altering each conic's control points and rho value in the data entry blocks titled "Lobe 1 Centerline" and "Lobe 2 Centerline" as shown in Table A- 4. Note that the start point of the second (aft) conic is automatically set as the end point of the forward conic. Each conic is defined by the three control points' X and Y values plus a single rho value. The number in small font in the Y column for Rho is not an input. Rho-value conics are explained in Section A5.3.3.

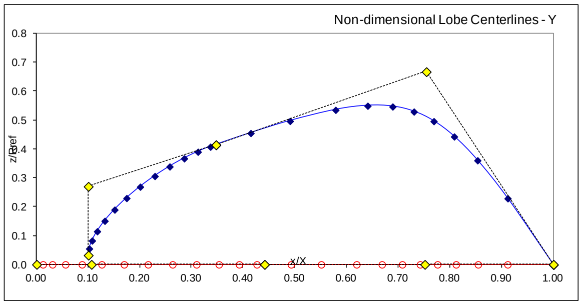


Figure A- 30. Lobe Centerline Definition Plot

Table A- 4. Inputs for Lobe Centerline Definition

	Lobe 1 Centerline			Lobe 2 Centerline	
	x	y		x	y
start point	0	0.00	start point	0.1	0.03
corner point	0.106	0.00	corner point	0.1	0.27
end point	0.4410	0.0000	end point	0.3470	0.4150
Rho	0.35	0.538	Rho	0.35	0.538
start point	0.44	0.00	start point	0.35	0.42
corner point	0.751	0.00	corner point	0.754	0.67
end point	1.00	0.00	end point	1.00	0.00
Rho	0.7	2.333	Rho	0.7	2.333

There are several key points regarding these inputs described in the following paragraphs.

If a one or three-lobe envelope is desired, the Lobe 1 centerline should be set to zero along its length as illustrated in Figure A- 30 and Table A- 4. This results in an envelope with a single center lobe as illustrated in Figure A- 31. If the Lobe 1 centerline is offset, then two mirrored lobes are created, along with a membrane at their centerline junction. An example of a resulting four-lobe envelope is shown in Figure A- 32. This figure also includes a cross section. The membranes between concave cusps are shown in bright green.

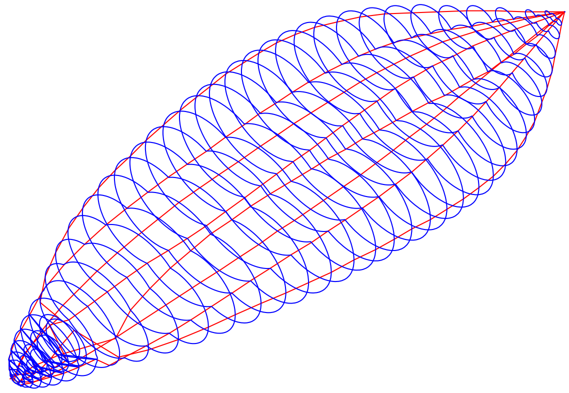


Figure A- 31. Three-Lobe Envelope

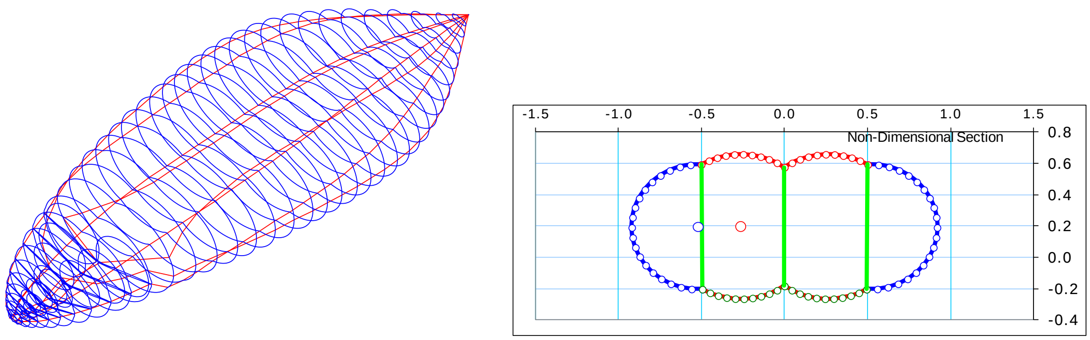


Figure A- 32. Four-Lobe Envelope and Cross Section

The tool does not require that the lateral value of the lobe centerlines start and end on the vehicle centerline (Y = 0). An extreme example of non-zero lobe start and end points is shown in Figure A- 33.

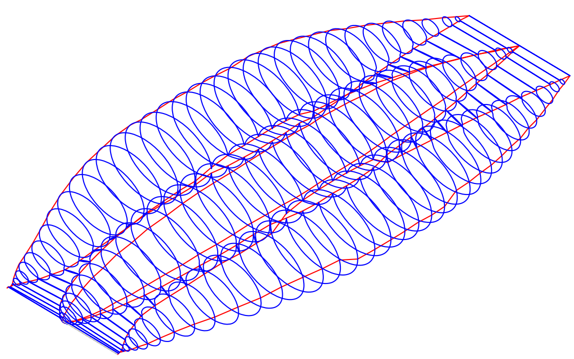


Figure A- 33. Example Showing Non-Zero Lobe Start and End Points

- Lobe centerline Z value

The vertical location of the lobe centerlines is specified in the data entry blocks labeled "Lobe 1 Centerline (X, Z)" and "Lobe 2 Centerline (X, Z)". These blocks control two rho-value conics in the same way as the lateral centerline (described above). These inputs permit the designer to camber the envelope or create a flat bottom, for instance.

It is worth pointing out that start and endpoint Z values need not be zero, or even positive values. Figure A- 34 provides a comparison of envelope side views. The envelope on the left has lobe centerlines that terminate at a Z-value of zero; on the right the lobes terminate at +0.20. This is reflected in the shape of the aft end of the envelopes.

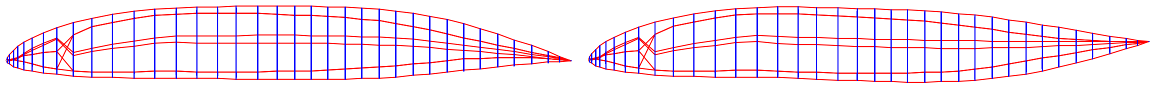


Figure A- 34. Example Effect of Vertical Lobe Centerline Variations

- Lobe radii versus length

The distribution of each lobe's diameter along its length is specified in data entry blocks labeled "Lobe 1 Radius" and "Lobe 2 Radius". This works in the same way as the centerline definition.

Figure A- 33 shows a three-lobe envelope in which the center and outboard lobes have similar radius distribution, as shown in Figure A- 35. A contrasting example is shown in Figure A- 36. Inputs for the outer lobe are unchanged from Figure A- 35, but the center lobe radii are doubled.

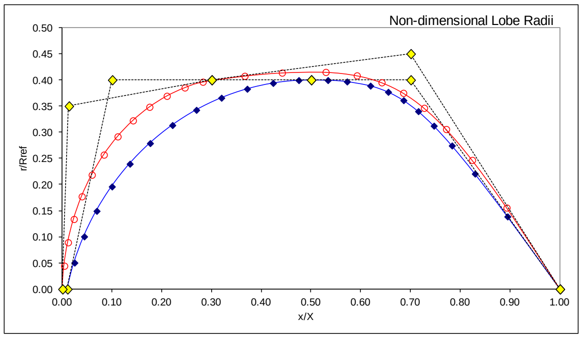


Figure A- 35. Example Plot of Radius versus Length

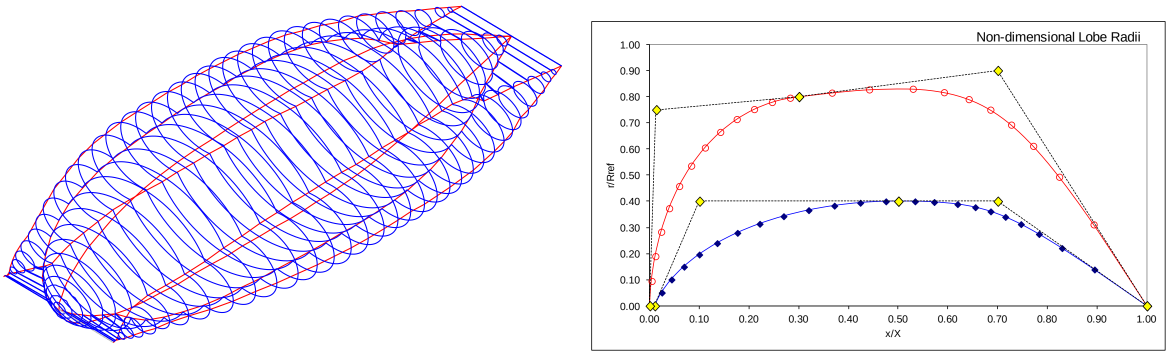


Figure A- 36. Contrasting Example of Radius versus Length

Overall and Reference Dimensions

Two additional inputs are required. These control the overall size and proportions of the envelope.

The first is the nominal overall length of the envelope, entered in the cell labeled “Overall Length”. This value is multiplied by the non-dimensional length in the two centerline and radii definition plots. If these non-dimensional lengths are greater or less than one, the actual overall length will be greater or less than the nominal overall length.

The second input is the “Reference Half-Span”. This is the lateral distance from the envelope centerline to the widest point of the envelope. This dimension scales the non-dimensional lateral and vertical offsets of the lobe centerlines as well as the non-dimensional lobe radii so that the envelope achieves the reference half-span.

The combination of these two inputs can be used to create a range of airship envelopes from common centerlines and radii. If the length and half-span are proportionally enlarged or diminished, the envelope size changes without change in proportion. If the length and half-span are disproportionately changed, the airship proportions change as well.

A6 GEOMETRY ON “LAYOUT” PAGE

A6.1 Layout Concept

This page defines geometry for engines, tail fins and a single gondola. These components are located and oriented by the designer with the help of a live view of the vehicle.

A6.2 Engine Geometry

As many as eight propulsion units may be defined. Each may be different. Check boxes to the left of the Engine Geometry input block activate each unit. The “propulsion unit” consists of a propeller, propeller spinner, engine nacelle and supporting pylon. Only six inputs are needed to define a representative unit:

- X, Y and Z: This defines the coordinates of the tip of the propeller spinner.
- Diameter: This defines the propeller diameter. The spinner and nacelle diameter is automatically scaled in proportion to the propeller diameter.
- Length: This defines the combined length of propeller spinner and nacelle. A negative length flips the engine from a tractor configuration to a pusher but the pylon does not move, leaving a nacelle that is not connected to the pylon. The pylon can then be adjusted by changing the Leading Edge x values (L.E.x) accordingly.
- Dihedral: This defines the angle of the pylon surface as seen in front view. As seen in the front view, zero degrees points the pylon to the right from the nacelle axis. 90° points straight upward from the nacelle axis.

Other characteristics of the propulsion unit are estimated on the basis of the six inputs.

- The projected span of the pylon is 1.5 times the propeller radius. This provides clearance between the propeller tip and airship surface. Note that the user is responsible for locating the nacelle and pylon – the tool does not automatically connect the pylon to the airship surface.
- The pylon leading edge is assumed to be un-swept. Its longitudinal location is 0.3 times the spinner/nacelle length behind the tip of the spinner.
- The pylon tip chord is set as 70% of the spinner/nacelle length; the pylon root chord is 150%.

Some aspects of the propulsion system definition are presented in Figure A- 37. In this front view, the engine installation on the vehicle’s right side (picture’s left side) is conventional. The installation on the vehicle’s left side has several problems. The propeller cuts into the envelope – either its diameter should be reduced or the propeller axis should be moved outboard. The engine pylon takes a lengthy path to the envelope surface – it would probably make more sense to aim it at the airship axis or to the closest point on the envelope surface.

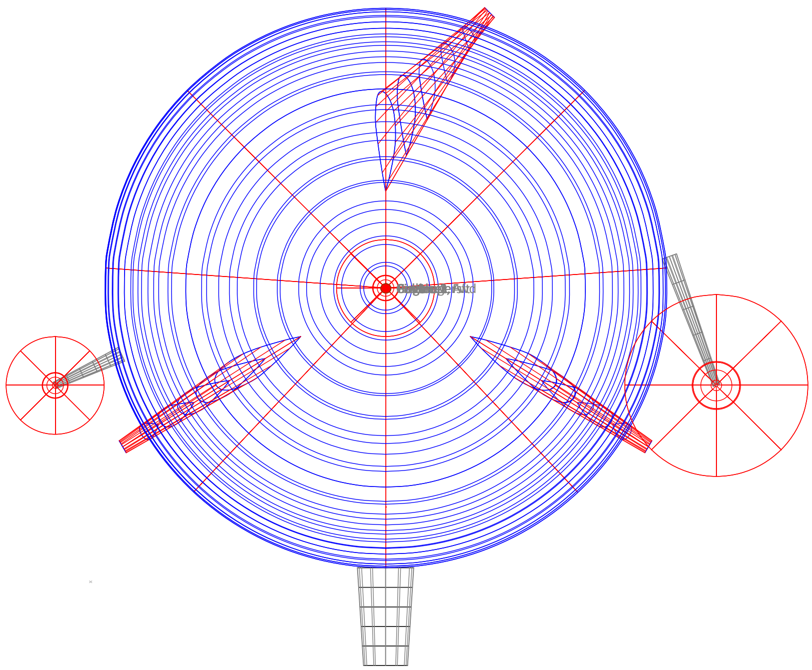


Figure A- 37. Front View Showing Unusual Component Installation

A6.2.1 Fin Geometry

Up to eight fins may be defined. These are typically provided for pitch and yaw stability and control but the user may choose to locate each at any point. Check boxes to the left of the Fin Geometry input block activate each fin – if the box is not checked, the fin is absent. Each fin is independently defined by nine input variables:

- Root location
- Dihedral angle: This defines the location of the fin leading and trailing edges at the root with respect to the airship axis (X-axis). An entry of zero degrees places the root on the port side of the airship; 90° places the root on the top of the airship, and so on. Note that this input does not influence the dihedral angle of the fin itself – it only defines the angle from the airship axis to the root.
- Radius at leading edge: This defines the radial distance from the airship axis to the leading edge at the root. This value may be adjusted to place the root leading edge on the airship surface. This is desirable so that an accurate fin wetted area calculation is made.
- Radius at trailing edge: This defines the radial distance from the airship axis to the trailing edge at the root. This value can be used to set the trailing edge on the airship surface.
- Fin dihedral angle: This defines the dihedral angle of the fin's 50% chord line about the root location. If the fin is located in a tapered region of the airship, selecting a fin dihedral angle different from the root location angle results in a change of incidence at the root but not at the tip. This results in a twisted surface. This twist is shown in the view but is not reflected in any calculation. Figure A- 37 illustrates this effect. The centerline fin is canted at a 45° angle about the line between its root leading and trailing

edges. The resulting incidence angle approaching the root is apparent in the figure – the tip incidence is unaffected by the dihedral angle.

- Fin flat span: This is the true span of the fin taken at the 50% chord line, where "true" means that the span is taken in the plane of the fin. The tip chord line is always parallel to the X-axis but the root chord may follow the airship taper as noted above.
- Fin root leading edge X coordinate: This longitudinal value in combination with the root location dihedral angle and radius at leading edge defines the three-dimensional location of the root leading edge.
- Fin root chord: This is the distance parallel to the X-axis between the fin root leading and trailing edges.
- Fin tip leading edge X coordinate: This input defines the X-coordinate location of the fin tip leading edge. In combination with the "fin root leading edge X coordinate", this value controls leading edge sweep.
- Fin tip chord: This is the length from the fin tip's leading edge to trailing edge. In combination with "fin root chord", this value controls fin taper ratio.

Other fin characteristics are approximated or estimated from the inputs above. These include:

- Fin thickness to chord ratio
- Fin incidence angle
- Fin control surface fraction and area

A6.2.2 Gondola Geometry

A single gondola may be defined. This is assumed to be on the vehicle centerline, with an adjustable vertical and longitudinal location. Gondola geometry is defined by a ceiling surface and a floor surface with a flat-wrap perimeter surface joining them. Eight inputs define the gondola:

- Vertical distance from center
- Front: This defines the distance between the airship axis and the leading edge of the ceiling surface. Negative values place the gondola ceiling above the vehicle centerline.
- Rear: This defines the distance between the airship axis of the trailing edge of the ceiling surface.
- Height and width
- Height: This defines the vertical distance between the floor and ceiling at the quarter length point of the ceiling. A positive value places the floor below the ceiling.
- Width/Length: This ratio defines the width to length ratio for both the ceiling and the floor. If the floor is shorter than the ceiling surface, it will also be narrower.
- Ceiling
- Front X: This is the X-coordinate of the ceiling leading edge.
- Length: This is the length of the ceiling from leading to trailing edge, projected onto the X-axis.
- Floor
- Front X: This is the X-coordinate of the floor leading edge.
- Length: This the length of the floor from leading to trailing edge. The ratio of floor length to ceiling length is the "taper ratio" of the gondola in both side and front views.

Other gondola characteristics are automatically calculated or assumed. These include:

- The shape of gondola curvature as seen in the top view.

A6.2.3 Discrete Masses

Up to 50 discrete point masses may be defined. These provide the basis for mass properties estimation of components beyond the airship envelope, such as fins, engines, gondola, payload, fuel, ballonets and so on. The mass properties of these are used in structural and whole-airship mass properties calculations. Each of the 50 items has six independent variables:

- Item: This is the user-selected name of the mass. This name is displayed on the View when the “Display Discrete Masses” checkbox is checked.
- X, Y and Z Coordinate: This defines the center of gravity of the point mass. This point is displayed as a red dot on the View when the “Display Discrete Masses” checkbox is checked. The mass is assumed to be a point mass. This means that it is assumed to have zero mass moment of inertia about its own center of gravity.
- Weight: This is the mass of the item in units of pounds-mass.
- Other: This column is provided for comments. These are not presently used by the tool.

A6.2.4 Detailed Inputs

The “Vehicle Layout” inputs described above are the primary geometric inputs needed by the tool. However, it is possible to fine-tune some components if this is needed. These detailed inputs are located in a series of vertical boxes to the right of the primary “Vehicle Layout” page. Input cells are highlighted in yellow. Detailed inputs are described below.

Fins 1 - 8

Detailed input blocks for each fin are located in each of four larger blocks labeled “Fin 1”, “Fin 2” and so on. The 12 available inputs define the coordinates of the fin root and tip airfoils. The root and tip airfoil proportions are assumed to be the same. They are also assumed to be symmetrical.

The first column of inputs is the chord fraction; the second is the vertical displacement in chord fractions of the upper surface. Note that the trailing edge is fixed at (1,0) and the leading edge is fixed at (0,0).

Gondola

A detailed input block for the shape of the gondola ceiling and floor is provided. The floor and ceiling are assumed to share proportions and are assumed to be laterally symmetric. Note that the final width/length of the gondola is defined in the primary gondola input block. This means that the shape defined in the detailed inputs should always have a maximum thickness of 1.000 (a half-thickness of 0.500). Changes in the detailed block are intended to pertain to the distribution of thickness along the length rather than absolute maximum thickness.

The first column of inputs is the gondola’s length fraction; the second is half-width in length fractions. Note that the trailing edge is fixed at (1,0) and the leading edge is fixed at (0,0). Remember that the maximum thickness should be held at 0.500.

Pylons 1 – 4

A detailed input block to control each engine pylon's root and tip airfoils is provided. This operates in the same way as the fin airfoil controls.

A7 MAIN WEIGHTS

A7.1 Weights Concept

This page is used to estimate airship mass properties including weights and inertias. These are used for sizing, performance and stability and control calculations.

A7.2 Weights Inputs

Most inputs on this page are made automatically in accordance with the airship selected on the Performance page.

Manual inputs focus on the longitudinal location of the center of gravity of selected components. This location is specified as a percentage of the length of the airship where 0% is the nose and 100% is the aft end of the envelope. Inputs are required for the following components:

- Volume-dependent components: nose reinforcement, ground handling
- Area-dependent components: solar cells
- Independent components: helium compression system, defensive measures, cargo bay
- Consumables elements: food and water, fuel, oil, water ballast at takeoff and removable payload/passengers

A7.3 Weights Outputs

Mass properties are provided in three major categories:

- Operating Empty Weight
- Consumables including fuel, oil, food and water and removable payload
- Lifting gas and enclosed air

Operating Empty Weight results are divided into four categories

- Volume dependent
- Area dependent
- Independent
- Other

Mass properties for each component are provided in terms of:

- Mass
- Center of mass in terms of longitudinal, lateral and vertical station
- Characteristic dimensions in three axes for estimation of mass moment of inertia
- Moments of inertia and products of inertia
- Location of component along the longitudinal axis
- Unit weight in terms of pounds per foot along the longitudinal axis

Mass properties for the airship as a whole are also provided:

- Mass, center of mass, center of buoyancy, mass moment of inertia

A vehicle weight summary is also provided.

Two approximations are notable. Buoyancy of all components except for enclosed air and lifting gas is zero due to its negligible volume. Fluidity of the enclosed air and lifting gas is ignored in the estimation of its mass moment of inertia – it is estimated as if it is solid. Additionally, moments of inertia do not include any apparent mass effects. These are handled in the Stability and Control module.

A8 SECTION WEIGHTS

The Section Weights page provides key information to the user but requires no input. This page divides the airship into a series of lateral-vertical slices (like an egg slicer) and computes the weight and buoyancy for each slice. This permits the computation and display of running moments such as that shown in Figure A- 38. The key running moment may be that of the “MTOGW with Lifting Gas”. This plot should end up at zero – if not, the airship is unbalanced in pitch and requires a modification to the longitudinal distribution of weight or buoyancy. This line can also indicate the extent to which bending moments are generated. If this line were always zero there would be zero running bending moment in a static case. Note that this page provides a blow-up of just the “MTOGW with Lifting Gas” line for fine-tuning of the design. An example is provided in Figure A- 39.

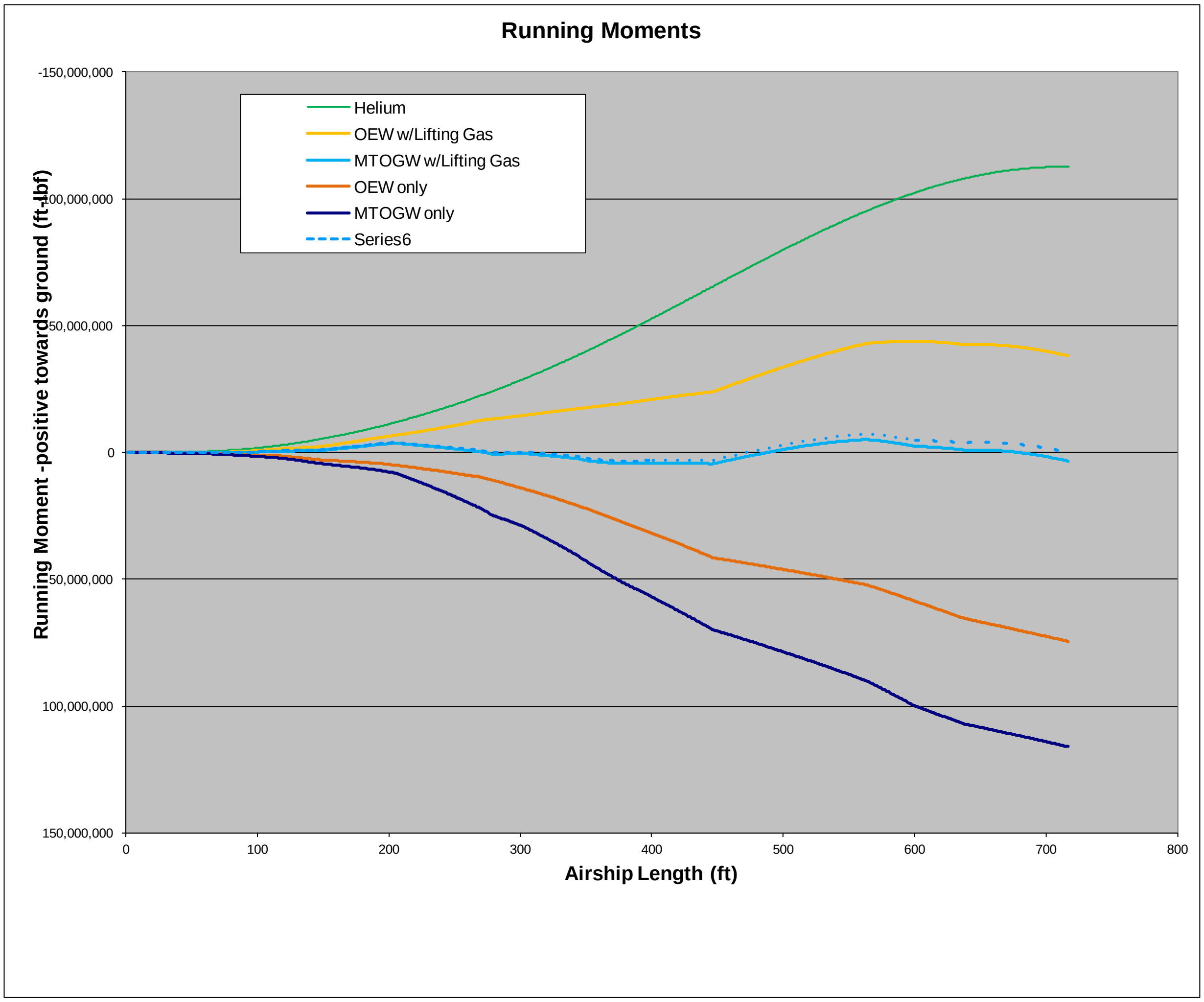


Figure A- 38. Running Moments

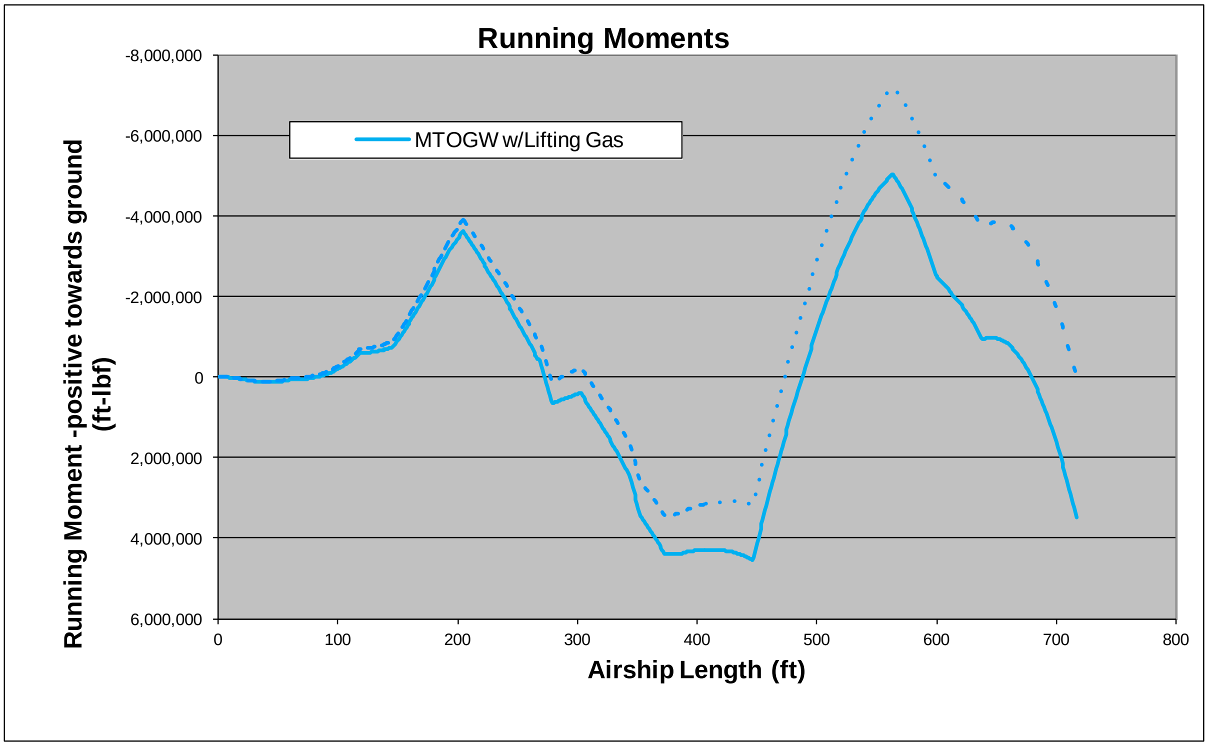


Figure A- 39. Magnified Running Moment of MTOGW with Lifting Gas

A9 LIFTING GAS

A9.1 Lifting Gas Concept

The Lifting Gas page brings together gas equations for air, helium and hydrogen. These are used primarily in the Performance and weights pages to determine volume needed based on maximum altitude and ground level fill requirements. There are no user inputs on the Lifting Gas page.

A10 PROPULSION TANKS

A10.1 Propulsion Tanks Concept

This page calculates the size and weight of fuel and ballast tanks. Cylindrical tanks with elliptical end caps may be specified. Variations on the inputs can create a spherical tank or a cylinder with spherical end caps. Weight is estimated based on tank material and skin thickness as well as estimated tank support structure and plumbing.

Separate inputs are made for fuel and ballast tanks. Multiple fuel tanks may be specified.

A10.2 Propulsion Tanks Inputs

A10.2.1 Tank Geometry

- The tanks assumed to be cylindrical with elliptical end caps. Inputs are:
- Internal radius. Internal radius of the cylinder
- Plug length. This is the length of the cylindrical section. This value may be zero to create a sphere or ellipsoid.
- Elliptical internal height. This is the depth of the elliptical cap. For example, a value of zero yields a flat cap on the cylinder. A value equal to the internal radius yields a hemispherical cap.
- Wall thickness. This is the average thickness of the tank wall. It may be considered to be a “smeared” thickness if the skin is stiffened or incorporates other structural elements.
- Material. This input is selected from a drop-down menu. This menu reads from a data table in Cells M10:N17.

A10.2.2 Other Tank Inputs

- Fuel type. This is selected from a pull-down menu that reads from Cells M20:M21.
- Manual input fuel density. One option from the pull-down menu above is “manual input”. This fuel density is selected when the user selects the fuel type “manual input”.
- Max altitude. This altitude input is used to estimate the maximum differential pressure experienced by the tank as it rises from sea level to this altitude. This assumes that the tank is not vented.

A10.3 Propulsion Tanks Outputs

The key outputs for this page are:

- Total fuel weight. This may be compared with total fuel needed in Cell H20 to guide adjustments to the tank geometry or quantity.
- Total fuel system dry weight
- Total ballast capacity
- Total ballast tank system dry weight

A11 CARGO BAY WEIGHTS

A11.1 Cargo Bay Weights Concept

The Cargo Bay Weights page is used to estimate the weight of the cargo bay or gondola. The gondola is simply modeled as box comprised of a floor, four walls, a ceiling and a cargo ramp. Material characteristics are specified, loads are simply estimated, and simple structures are sized and weighed.

The cargo bay structure is assumed to be supported by the envelope from its upper perimeter. Other assumptions include:

- Landing gear loads are not imposed on the cargo bay.
- Engine pylons are not attached to the cargo bay.
- Weights of systems in the cargo bay are not estimated in this section. These systems include avionics, furnishings, environmental control, lighting and so on.
- The cargo bay is not pressurized.
- Inertial loads on the cargo bay are estimated at the specified g-load. Inertial loads on the ramp are estimated at 1.0 g (the ramp is assumed to be unloaded in flight).

The cargo bay is assumed to be unpressurized; all loads arise from the inertial loads of the payload – the weight of the structure is assumed to be insignificant.

A11.2 Cargo Bay Weights Inputs

Inputs are divided into six sections as described below.

A11.2.1 Strength and Loads

These inputs define the limit strength of the cargo bay structure, the structural material density and the airship G-limit. The limit strength is the greatest nominal stress that may be seen within the normal flight envelope of the airship.

A11.2.2 Cargo Bay Dimensions

The length, width and height are specified. These dimensions are independent of the cargo ramp so if the cargo ramp intrudes into the basic cargo bay, the cargo bay dimensions (length, presumably) should be reduced to compensate.

A11.2.3 Cargo Floor Characteristics

These inputs describe the load and basic structural design of the cargo floor.

- Cargo Bay Floor Load is the total 1-g load on the cargo floor in pounds.
- Cargo Bay Floor Width/Depth Ratio specifies the proportions of the floor as seen in a transverse cross section. This ratio drives the floor beam depth and has an important effect on the floor structure weight. Note that the floor beam weight is computed without the weight of the web, so very deep floors will result in unrealistically low floor beam weights. Note also that the beam cap cross section is assumed to be constant, a conservative (heavy) assumption, so this addresses the web weight to some extent.

- Floor Load Concentration Factor specifies the ratio between the average load experienced by the floor and the worst-case concentrated load. This is taken as a beam load across the full width of the cargo bay as opposed to an area load (of, for example, a tire contact patch). A concentrated load might result from rolling stock (a truck for example) for which a single axle's load might be focused on a single floor beam. The floor beam is sized to handle the average load times the load concentration factor. The transverse floor beams are assumed to be space one foot apart.
- Floor Areal Weight is the average weight of the floor structure not counting the floor beams. This weight includes the floor planking and outer (aerodynamic) skin. cargo handling system weight from rails, rollers, locks and tie-down fittings are addressed in a later "Cargo Handling System Areal Weight" input, see Section A11.2.6.

A11.2.4 Ramp Characteristics

These inputs define the dimensions, loads and areal weight of the cargo ramp.

- Ramp Length and Width are specified in feet. If there is no ramp, don't enter zero – this will result in "divide by zero" errors. Instead, enter a very small number such as 0.0001.
- Ramp Maximum Load. The ramp load is taken at 1.0 g - it is assumed that the ramp is not loaded in flight. The user can multiply the ramp 1.0 g load by the Airship G-limit if the ramp is to be loaded in flight
- Ramp Width/Depth Ratio. This input describes the proportions of the ramp as seen in a transverse cross section. This is the same concept as for the Cargo Bay Floor Width/Depth Ratio. The resulting depth is used for the longitudinal and transverse beam depths. These are assumed to be uniform in depth, so the Ramp Width/Depth Ratio should be chosen as representative of the ramp as a whole.
- Ramp Load Concentration Factor. This factor, as for the cargo bay floor, influences the strength and weight of the transverse beams.
- Ramp Areal Weight. This, as for the cargo bay floor, is the estimated weight of the cargo floor planking and outer aerodynamic skin. Weight of cargo handling components on the ramp such rails, rollers, locks and tie-down fittings are to be added to the ramp areal weight.

A11.2.5 Installation Factors

These factors account for the non-optimum nature of real beams and columns that are connected to other components and may require stabilization for buckling and crippling.

- Beam Installation Factor. This factor adjusts the weight of the transverse beams in the floor and cargo ramp.
- Column Installation Factor. This factor adjusts the weight of the wall columns.

A11.2.6 Areal Weights

Areal weights for the walls, cargo handling system and ceiling are entered in this section.

- Wall Areal Weight. This weight per unit area is multiplied by the total wall area to estimate the wall weight exclusive of the wall column weight that is automatically estimated.

- Cargo Handling System Areal Weight. This weight per unit area is multiplied by the total cargo bay floor area to estimate the cargo bay's cargo handling system weight. As noted above, this factor is not applied to the cargo ramp.
- Ceiling Areal Weight. This weight per unit area is multiplied by the cargo bay floor area to estimate the ceiling weight. This weight includes all ceiling structure.

A11.3 Cargo Bay Weights Calculations

This section describes the computations for each component of the cargo bay.

A11.3.1 Floor

The concept of the floor structure is that the floor is supported by full-width transverse beams that are supported at their outboard ends by columns ascending to an unspecified support at the envelope. The transverse floor beams are assumed to be spaced on one foot centers. The beams are planked with flooring to distribute concentrated loads fore and aft to multiple floor beams, reducing the load concentration factor. The floor load is assumed to be evenly distributed; all floor beams are assumed to be the same. There is also an outside, aerodynamic skin.

Each floor beam is assumed to have a load evenly distributed along its length. This load is the uniform load times the load concentration factor. The maximum bending moment (at the beam's center) is calculated. The beam is assumed to be an "I" beam of constant cross section. The caps are sized at the beam center; the web weight is assumed to come from the excess cap weight in the outboard regions of the beams. The beam weight is then computed based on the material density and the installation factor. The weight of all beams and the areal weight of the floor are added to obtain the total floor weight (without cargo handling systems).

A11.3.2 Ramp

The concept of the ramp structure is that the ramp surface is supported by transverse beams that connect to three longitudinal beams located at the center and outboard edges of the ramp. The three longitudinal beams carry the load forward to a hinge at the cargo floor and aft to a support on the ground. The ramp is assumed to carry no load in flight – its loads are estimated at 1.0 g. The ramp decking distributes concentrated loads fore and aft to multiple transverse floor beams, reducing the load concentration factor. There is also a thin aerodynamic skin on the ramp's outer surface.

The longitudinal beams are conservatively sized. The entire ramp load is assumed to be concentrated in the middle of the ramp. This is assumed to load each longitudinal beam with one-third of the total load at the center of each longitudinal beam. The moment is calculated and the required cap size is estimated. This is assumed to be constant over the length of the beam. This excess weight is assumed to make up for the absence of a web. An installation weight factor is applied and the beam weight is calculated.

The transverse beams are sized and weighed using a process similar to that for the cargo floor (Section A11.3.1). One difference is that the transverse beams span only half the width of the ramp, between the three longitudinal beams. The ramp deck weight is calculated as the product its areal weight and the ramp area. The total weight of the ramp is the sum of the longitudinal beams, transverse beams and deck weight.

A11.3.3 Walls

The concept of the wall structure is that the end load from each transverse floor beam is carried upwards by a discrete column. The columns are connected with a skin structure for shear strength and to provide an aerodynamic surface. The upper ends of the columns connect to unspecified structure that is not included in the cargo bay weight calculation.

The end load of each transverse floor beam is calculated, including the load concentration factor and g-loading. The column cross section area is sized to handle this load at the specified stress level. The weight of each column is calculated based on its cross section area, material density and column installation factor. The total weight of the columns is the sum of each column weight – note that the columns are assumed to be present only in the lateral walls of the cargo bay.

The wall skin-related weights are the product of the total wall area and the wall areal weight. The total wall weight is the sum of the skin-related weights and the column weight.

A11.3.4 Ceiling

There is no structural concept for the cargo bay ceiling – it is assumed to be lightweight structure without inertial or aerodynamic loads. Its weight is the simple product of the cargo bay floor area and an input areal weight.

A11.3.5 Cargo Handling Systems

The cargo handling systems are assumed to play no role in the general structure of the cargo bay. Instead, the cargo handling systems provide an interface between the cargo and the cargo floor decking and transverse beams. Cargo handling systems weights are estimated as a product of an areal weight and cargo floor area. The idea is that the areal weight of other cargo aircraft cargo handling systems can be quantified to provide a basis for the areal weight input in this section.

A11.3.6 Total Cargo Bay Weight

The total cargo bay weight is simply the sum of the floor, ramp, wall, ceiling and cargo handling system weight.

A12 AIR CUSHION LANDING SYSTEM (ACLS) WEIGHTS

A12.1 ACLS Concept

Air cushion landing systems (ACLS) as employed on airships are a form of landing gear that in one mode resembles a hovercraft attached to the bottom of the airship. In this mode, the ACLS is pressurized with fans to lift the airship and provide a low-friction means of motion along the ground. This mode is useful for airships that are less than fully buoyant. It can enable taxi, takeoff and landing "roll". In a second mode, ACLS can provide suction, holding the airship firmly against the ground surface. This mode enables the airship to be docked at locations without docking infrastructure such as a mast. The suction mode is useful during cargo transfer operations and is especially useful when the airship is positively buoyant as well as in windy conditions.

It is a feature of ACLS that landing loads are distributed over a large area. This characteristic is in accordance with the typical lightweight, distributed structure of airship envelopes.

The ACLS page estimates the capacity and weight of an ACLS based on its dimensions and operating conditions. Inputs to this page are described below.

A12.2 ACLS Inputs

Inputs to the ACLS page are described.

- ACLS Height. This is the depth of the ACLS as measured between the ground and the lowest point of the airship envelope when the ACLS is in the pressurized mode.
- ACLS Maximum Vertical Height from Envelope. This is the distance from the ground to the envelope at the lateral edge of the ACLS. This input assumes a circular envelope cross section and is used to define the width of the ACLS. A larger input moves the boundary of the ACLS outboard where there is a greater distance between the ground and envelope.
- Ground Wind Speed. This defines the operating limit for the airship. This wind speed may be at right angles to the airship's longitudinal axis.
- Airship Length, Height and Width. These inputs are automatically entered according to the airship selected on the Performance page.
- Lateral Cross Section Knockdown Factor. The airship maximum cross section is estimated from Performance page data. This factor is applied to the maximum cross section to represent the effective cross section of the airship as a whole as a basis for drag force and rolling moment estimation.
- Ground Coefficient of Friction. This input defines the coefficient of friction between the ACLS and the ground surface. This, in combination with the total airship force against the ground, is used to determine the maximum side-force the airship can generate.
- Air Density. Air density and Ground Wind Speed are used to calculate the dynamic pressure of the wind.
- Coefficient of Drag. Coefficient of drag, reference area and dynamic pressure are used to estimate the lateral aerodynamic force on the airship when stationary on the ground. The

reference area is the product of Airship Length, Airship Height and Lateral Cross Section Knockdown Factor.

- Suction Pressure. This is the suction pressure within the ACLS when in the suction mode. This value is used to compute down-force, limit of aerodynamic side-force and limit tip-over moment.
- Max ACLS/Envelope Length. This input defines the length of the ACLS as a fraction of the overall envelope length. This fractional input adjusts the ACLS as the envelope is changed in size.

A12.3 ACLS Calculations

- Maximum and Design ACLS Width. The maximum ACLS width is geometrically calculated. It is based on the difference between ACLS Max Vertical Height from Envelope and ACLS Height assuming an elliptical cross section with the specified Airship Height and Airship Height. This is the width at which the ACLS height reaches the value specified in ACLS Max Vertical Height from Envelope. Design ACLS Width is based on a tip-over angle determined by the Ground Coefficient of Friction and the height of the drag center of pressure (half the envelope height plus ACLS height).
- Maximum ACLS Length is the product of the envelope length and the ACLS fraction of envelope length specified in Max ACLS/Envelope Length.
- Maximum Hold Down Force. This is product of Suction Pressure and ACLS area (length x width).
- Drag Force (F_d). This is the aerodynamic force exerted on the airship in a direct crosswind of the strength specified in Ground Wind Speed. It is the product of side area and dynamic pressure. Side area is the product of Airship Length, Airship Height and Lateral Cross Section Knockdown Factor.
- Moment from Envelope Drag. This is the aerodynamic moment generated by the Drag Force about an arm equal to one-half of the envelope height plus ACLS Height. Secondary contributions to rolling moment due to lift or down-force are disregarded.
- Sideslip Case. These calculations estimate the minimum required ACLS footprint area to resist lateral sliding under pressure from a crosswind.
- Footprint area is the Drag Force divided by the product of Ground Coefficient of Friction and Suction Pressure.
- Minimum ACLS Length is the footprint area divided by the Design ACLS Width.
- ACLS Perimeter is the perimeter of the assumed-to-be-rectangular ACLS.
- Rollover Case. These calculations estimate the minimum required ACLS dimensions to resist rolling over under pressure from a cross wind. The Design ACLS Width is assumed – this leads to the same size ACLS as for the Sideslip Case.
- Minimum ACLS Length. This calculation assumes that the ACLS width is equal to the Design ACLS Width. The calculation sets the suction force times the ACLS footprint area times half the ACLS width equal to the Moment from Envelope Drag. Since the ACLS width is known, the ACLS length can be calculated. Note that this calculation assumes a neutrally-buoyant airship – all resisting moment is provided by suction.
- Minimum Area is the product of Minimum ACLS Length and Design ACLS Width.
- ACLS Perimeter is the perimeter of the assumed-to-be-rectangular ACLS.

- Equivalent MTOGW. There is a historical relationship between ACLS area and ACLS perimeter and MTOGW. These historical relationships are represented as algorithms. Equivalent MTOGW is estimated using both algorithms.
- ACLS Weight as a fraction of MTOGW is estimated with an historical algorithm, based on the heavier of the two Equivalent MTOGW weights. ACLS Weight is then estimated as this fraction times the heavier of the two Equivalent MTOGW weights.

A13 STABILITY AND CONTROL

A13.1 Stability and Control Concept

The stability and control page analyzes the vehicle's geometry to estimate the handling qualities of the proposed design. In particular the page performs a tail sizing analysis, trims the aircraft at various conditions, produces linear bare airframe models, and performs non-linear simulations of vehicle response to perturbations.

A13.2 Stability and Control Inputs

The stability and control module requires numerous inputs of vehicle geometry and aerodynamics from other modules in the tool, and are not required for the user to modify. These cells are colored orange. Cells colored green or gray are outputs of the module and should not be edited by the user. In addition, the user must supply a number of parameters and has the option to ignore certain calculated parameters and replace with his own values for use in parametric studies. The user specified cells are colored yellow or are check boxes. A description of the user specified parameters is detailed in the following sub-sections.

A13.2.1 Ballonet Properties

The user must supply the maximum forward and aft displacement from the station line of the center of volume of the hull of the center of buoyancy attainable by the ballonet system in units of feet.

A13.2.2 Envelope Aerodynamic Properties

The user has the option to either use the hull aerodynamic coefficients generated by the aerodynamics module, or supply the coefficients manually. Check boxes are used for the user to configure which aerodynamic method the stability and control routine should use. The force coefficients are normalized by volume$^{(2/3)}$ and the moment coefficients are normalized by volume$^{(2/3)}$. The user supplied aerodynamic coefficients are listed below in Table A- 5.

Table A- 5. User Supplied Aerodynamic Coefficients

Acronym	Description
Cl_alpha	Lift curve slope
Cl0	Lift coefficient at zero degrees angle of attack
Cd_alpha	Drag curve slope
Cd0	Drag coefficient at zero degrees angle of attack
Cmm_alpha	Pitching moment curve slope
Cmm0	Pitching moment coefficient at zero degrees angle of attack
Cy_beta	Side force curve slope
Clm_beta	Rolling moment coefficient curve slope
Cnm_beta	Yawing moment coefficient curve slope

A13.2.3 Fin Properties

The user has the option to enable/disable the fins for the stability and control analysis through the use of check boxes for each fin. Most of the fin information is provided to the stability and control routine from other modules, but the user does need to provide some information for each fin. The user must specify the hull/fin aerodynamic interference factor and the gearing from pitch and yaw control to fin flap angles. The hull/fin aerodynamic interference factor is used to create an effective fin area. The factor is added to unity and the sum is multiplied by the physical fin planform area to create the effective fin area.

The routine assumes the fins are oriented in a radial manner from the vehicle's longitudinal axis with no incidence angle. The radial angle is calculated based upon the lateral and vertical offsets of the fin aerodynamic moment arm. A lateral fin will have a radial angle of zero, with a counter-clockwise rotation being the positive direction. For each fin, a positive flap command generates lift perpendicular to its radial axis, generating a counter-clockwise roll moment. Figure A- 40 below illustrates the direction of the increased lift generated by a positive flap deflection as viewed from behind the vehicle. The user must specify the gearing for both a pitching moment control and yawing moment control command to individual fin flap deflection. This information is used by the simulation trim routine. The user can specify up to 8 fin surfaces.

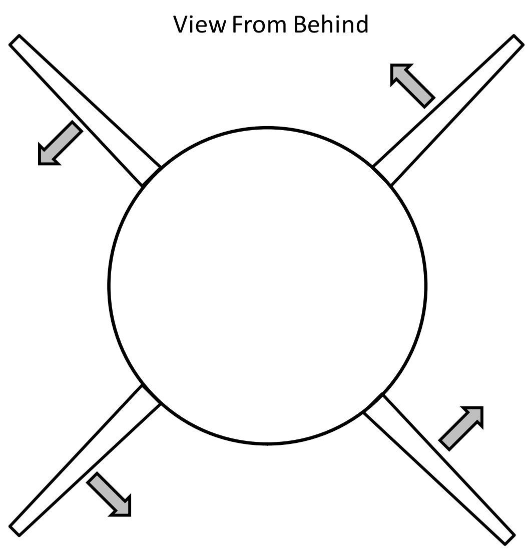


Figure A- 40. Aft View of Airship Showing Control Surface Deflection Convention

A13.2.4 Propulsion Properties

Propulsion devices are modeled as force generators at their location on the hull. The stability and control routine gets the relative position of the thrusters relative to the center of volume of the hull in units of ft (positive forward, right, and down). The user then specifies the thruster relative pitch and heading angles for the direction of applied thrust from the hull in units of degrees, as well as the maximum thrust and reverse thrust capabilities of the devices in units of pounds. The user must also specify the gearing of thrust, pitch, and yaw commands to each thruster. Each thruster can be enabled/disabled through the use of check boxes.

A13.2.5 Excess Drag Properties

Non-lifting bodies such as gondolas can be modeled through the use of the excess drag properties section. These models are enabled/disabled by the use of check boxes. The user must specify the three dimensional location of the drag item in relation to the center of volume of the hull in units of feet (positive forward, right, and down). Drag is modeled as the same in all flow directions, and specified by a drag coefficient and drag area (ft^2). The user can specify up to 8 different drag items.

A13.2.6 Simulation Trim Parameters

The stability and control routine allows the user to specify a desired airspeed and flight path angle to trim at. Desired airspeed is specified in units of knots, and flight path angle in units of degrees (positive values indicate a climb). The trim routine can be configured to use a ballonet or elevators for trim pitching moment control, and is selected via check boxes. It is not recommended to use both trim methods simultaneously.

The user is given the option to specify the initial condition of the control devices for the trim routine in the event the model does not converge. Pilot controls for the initial condition are specified in units of percent input (+/- 100%), and pitch attitude in units degrees. A trim step size factor variable is also available to the user to help with convergence. Reducing the factor below a value of one will reduce the step size of the trim routine, increasing the likelihood of achieving trim.

A13.2.7 Simulation Data Recording

The user must specify the folder in which the simulation trim and time history data will be saved.

A13.2.8 Perturbation Simulation Properties

This section allows the user to specify which bare airframe disturbance perturbation simulations to perform. A perturbation magnitude of zero is interpreted as the desire to not perform that particular perturbation simulation. The perturbations are applied as step changes to the parameter of interest in the absence of pilot or stability augmentation system feedback. The user also specifies the simulation time length. For all cases the perturbation is applied at the 5 second mark.

A13.3 Stability and Control Calculations

A13.3.1 Calculate Virtual Mass Properties

The virtual mass properties of the hull are approximated using an equivalent ellipsoid method. The routine uses tabulated results for various ellipsoid shapes, and interpolates between the breakpoints. The tabulated coefficients used are detailed in NACA report No. 323, “Flow and Force Equations For A Body Revolving In A Fluid”, tables III and VI.

The fineness ratio is also estimated for use in estimating the destabilizing pitching and yawing aerodynamic moments of the hull for use in the fin sizing analysis.

A13.3.2 Fin Size Analysis

To analyze the fin size of the vehicle a moment balance is performed between the destabilizing hull aerodynamics and stabilizing (or destabilizing) fin aerodynamics. Because airships require sideslip to turn and the vehicle dynamics are very slow, it is common for airships to be intentionally designed slightly unstable aerodynamically in the directional axis. Rudder or differential thruster inputs generated by the pilot or a stability augmentation system then stabilize the axis. The pitch axis has the added stabilizing effect of the center of gravity typically being below the center of buoyancy, creating a restoring pitch moment. It should be noted, that because the pitch axis has both aerodynamic and inertial moments the required fin area for neutral stability will vary with dynamic pressure. Higher speeds require a larger vertical tail area. While the vertical fins do not need to be as large as the horizontal to achieve stability, from a manufacturing standpoint it may be desirable for all fins to be the same.

This routine calculates the required fin area to achieve neutral stability in both the pitch and yaw axes for the given hull geometry, as well as compares that area to the current design. The routine follows the methods outlined in NACA report number 405, "Application of Practical Hydrodynamics to Airship Design". It also provides the user information on the fin size requirements for neutral stability for a conventional circular cross section ellipsoid of varying fineness ratios to provide the sensitivity of stability due to hull geometry changes.

To estimate the aerodynamic moments of the hull an ellipsoidal approximation is applied using the virtual mass properties calculated in the previous routine. As a comparison, fin size requirements for neutral stability of an ellipsoid with circular cross section of the same volume are also calculated for a range in fineness ratios (length/diameter). For these cases the fin longitudinal moment arm is held at the same normalize distance from the nose.

The plots below in Figure A- 41 are example outputs of this routine. The first shows the estimated total vertical tail area required for neutral directional stability. The elliptical hull geometry with a circular cross section is shown by the blue line labeled "Ellipsoidal". The blue star marker represents the predicted total vertical tail area required for neutral static stability for the user specified hull geometry. The cyan triangle marker labeled "Actual" represents the effective total vertical tail area of the user specified design. If the user designed tail area is less than the tail area required for neutral stability, then the vehicle will be statically unstable in that axis. The equivalent tail area of the user design is computed as the projected area on the vertical and horizontal axes in the case the tail configuration is not aligned with the primary axes.

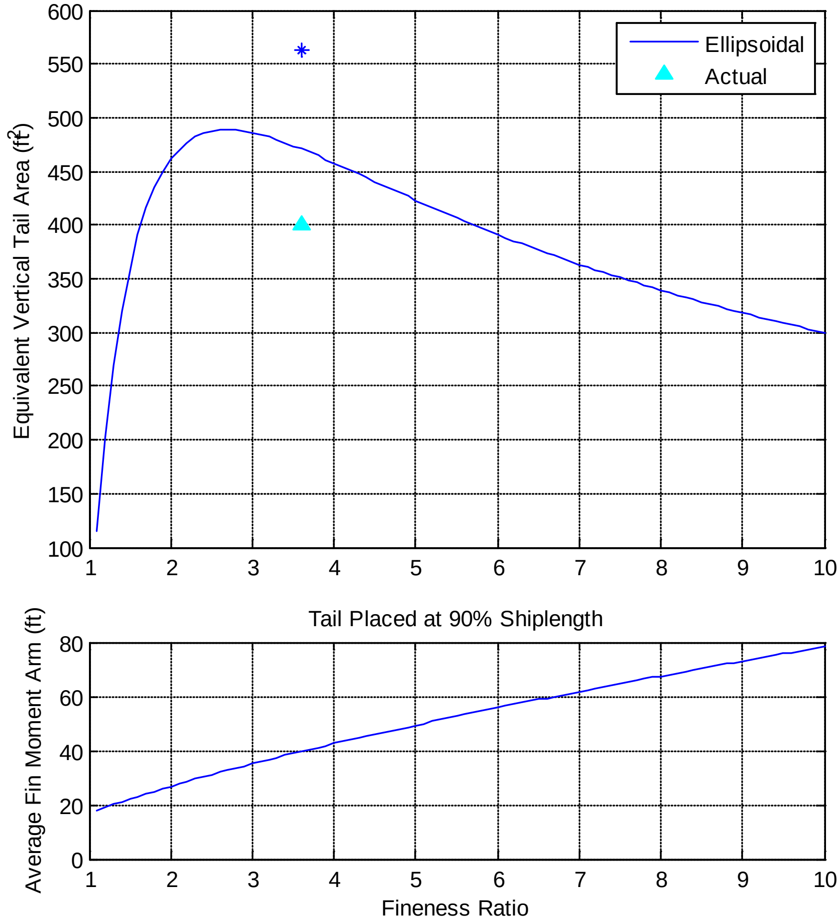


Figure A- 41. Equivalent Vertical Tail Area and Average Fin Moment Arm

The pitching moment is a function of dynamic pressure, so horizontal tail area required for neutral static stability is analyzed at multiple airspeeds. For the plots shown in Figure A- 42, the color of the line or star marker indicates the airspeed the analysis was performed at, again with the line representing an ellipsoidal hull with circular cross section and the star marker using the user specified design.

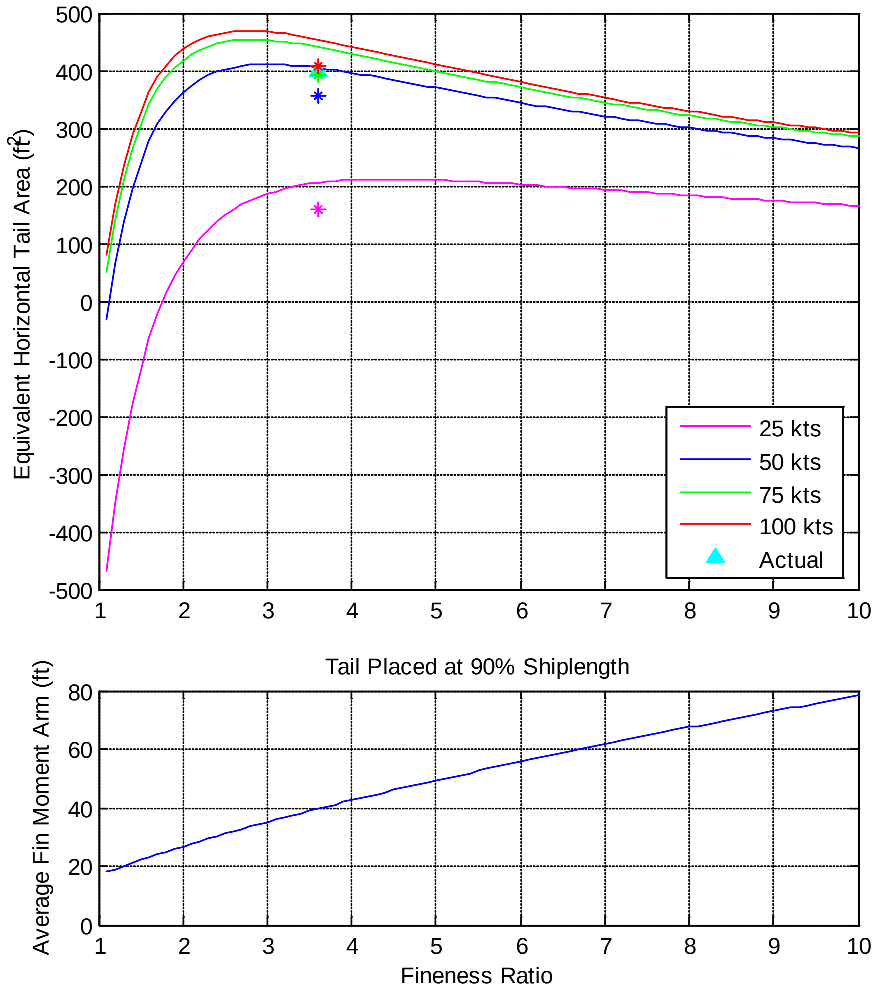


Figure A- 42. Equivalent Horizontal Tail Area and Average Tail Moment Arm

Airships do not perform coordinated turns because they do not actively control their bank angle. Instead the method of turning involves holding a sideslip. The turning radius can be calculated as a function of sideslip angle, with the ability to achieve a given sideslip angle typically being limited by thrust capability or structural loads. The plot below in Figure A- 43 shows an example of what the routine outputs for turn radius estimation as a function of sideslip.

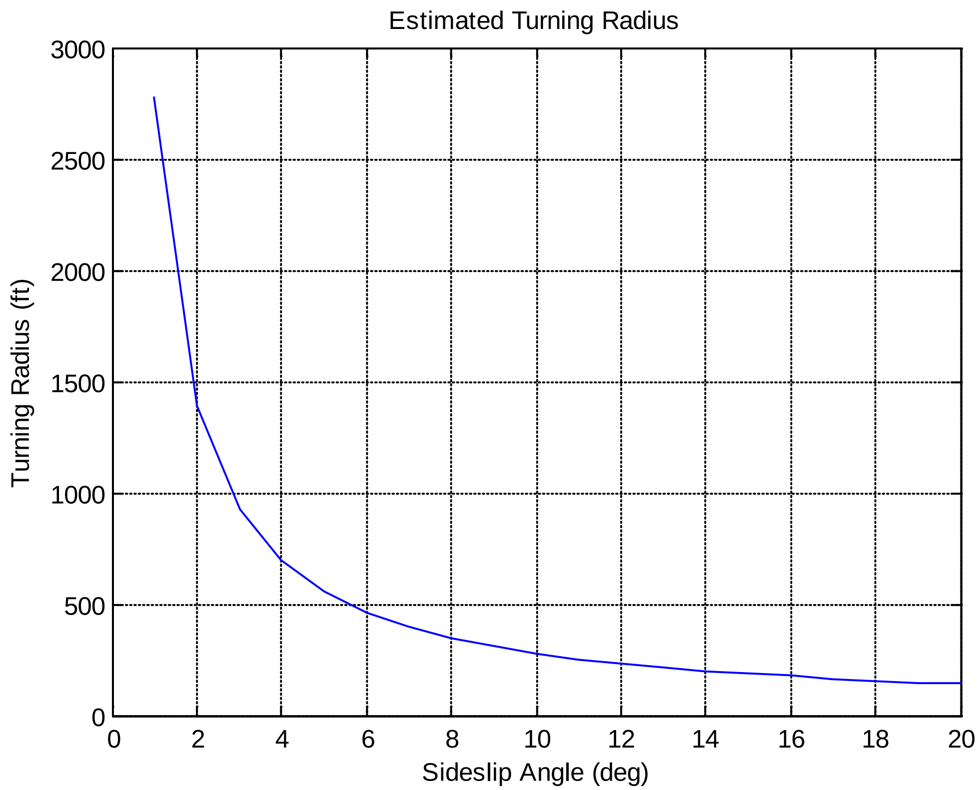


Figure A- 43. Estimated Turning Radius

The horizontal and vertical equivalent fin areas can be compared to the fin areas required for neutral static stability to produce static stability ratios. In steady turning flight, the vertical equivalent fin area can also be compared to the fin area required to balance aerodynamic sideforce during a turn. These stability ratios are calculated and presented to the user. Example plots of these results are presented in Figure A- 44 and Figure A- 45 below. The ratio is presented as a function of aerodynamic angle, with the horizontal stability ratio also being a function of airspeed.

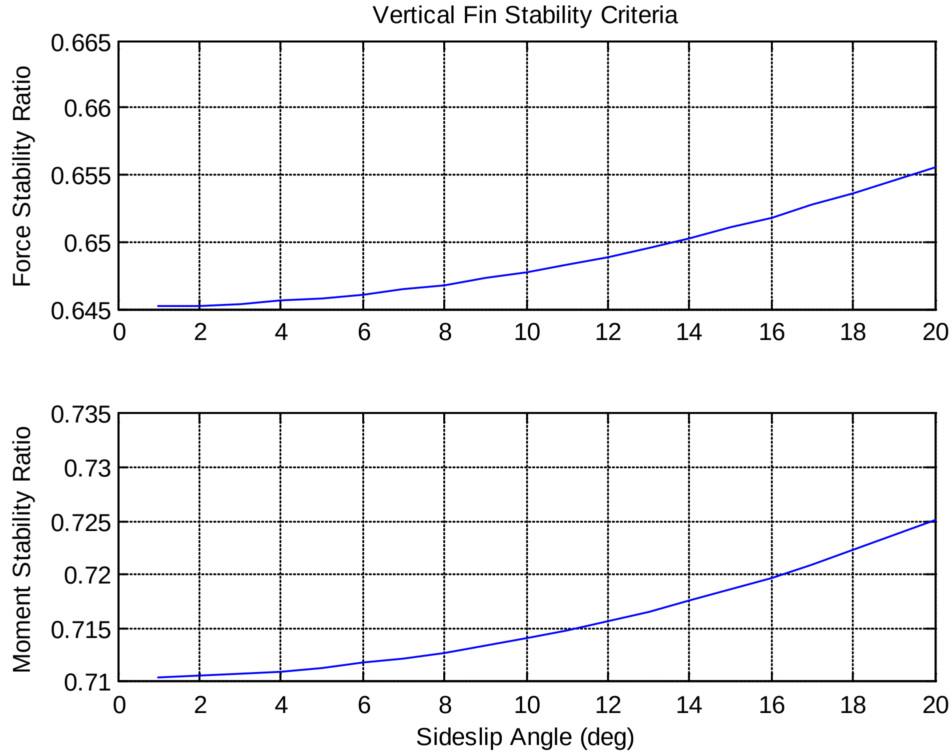


Figure A- 44. Vertical Fin Stability Criteria

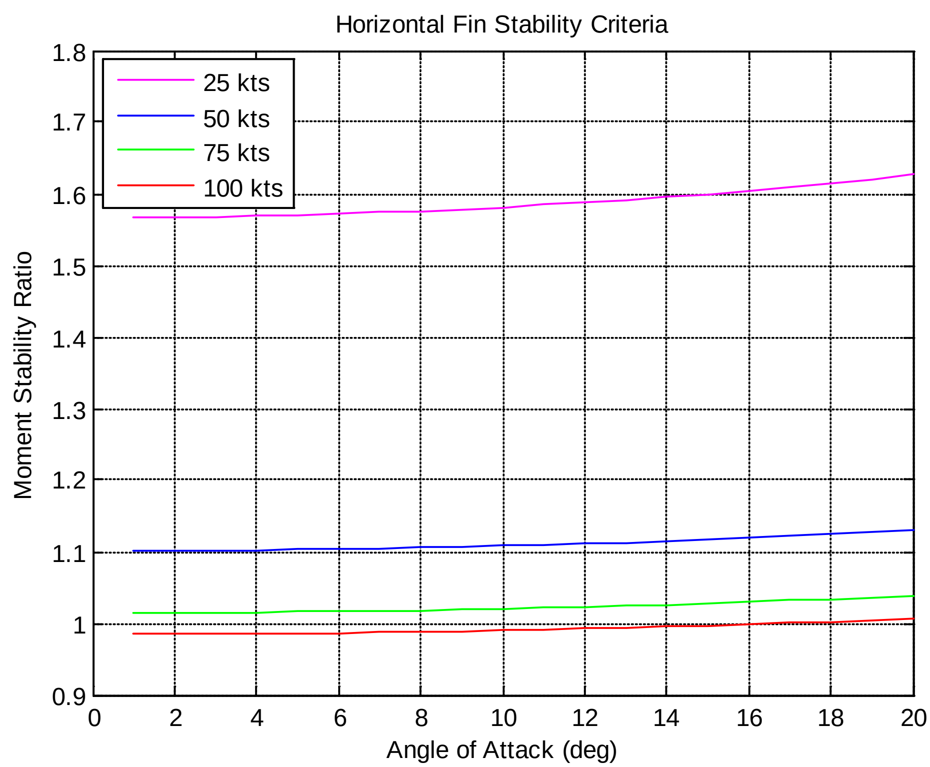


Figure A- 45. Horizontal Fin Stability Criteria

A13.3.3 Trim the Aircraft

A six degree of freedom non-linear simulation model of the vehicle is included in the module. A Jacobian based trim routine is used find the control positions and vehicle states which produce zero acceleration at the desired condition. The user can define the desired airspeed, flight path angle, and heading. Information detailing the trim process is recorded in the file trim.dat in the user specified data recording folder. This file shows for each iteration what the acceleration, attitudes, and control input values are. Descriptions of the trim data contained in these files and their associated units are shown in Table A- 6.

Table A- 6. Trim Data

Acronym	Description	Units
udot	Longitudinal Body Axis Acceleration	ft/sec^2 (Positive Forward)
vdot	Lateral Body Axis Acceleration	ft/sec^2 (Positive Right)
wdot	Vertical Body Axis Acceleration	ft/sec^2 (Positive Down)
Pdot	Roll Acceleration	deg/sec^2
Qdot	Pitch Acceleration	deg/sec^2
Rdot	Yaw Acceleration	deg/sec^2
phi	Roll Attitude	deg
theta	Pitch Attitude	deg
psi	Heading Angle	deg
del_th	Thrust Command	%
del_r	Yaw Command	%
del_e	Pitch Command	%
del_b	Ballonet Command	%

In the event that the trim routine does not converge, the user has the option of specifying a different initial condition as well as altering a factor on the step size. Reducing the value of the trim step size factor below one will increase the likelihood of a successful convergence, but will take more iterations to achieve success.

A13.3.4 Trim the Aircraft and Linearize

This function will trim the aircraft at the user specified condition, and then print out a linear aircraft model. The linearization routine is a two-sided perturbation method numerical approach. The step sizes of the perturbations cannot be changed by the user, but have been sized to provide good results for vehicles without large non-linear effects.

A13.3.5 Trim, Linearize, and Perform Bare Airframe Disturbance Simulations

This function will trim the aircraft at the user specified condition, print out a linear aircraft model at the trim condition, and then perform non-linear time history simulations of the vehicle responding to the user specified perturbations. Each time history will be saved in the user specified data recording folder with file names disturbance_simulation_XX.dat, where XX corresponds to the file index number labeled in the perturbation size input section of the tool. The format of the output data file is fixed width spacing, with descriptions of the variable names detailed in Table A- 7 below. An example of the simulation results for a longitudinal speed perturbation is shown in Figure A- 46 below.

Table A- 7. Variable Name Descriptions

Acronym	Description	Units
t	Simulation Time	sec
u	Longitudinal Body Axis Velocity	ft/sec (Positive Forward)
v	Lateral Body Axis Velocity	ft/sec (Positive Right)
w	Vertical Body Axis Velocity	ft/sec (Positive Down)
P	Roll Rate	deg/sec
Q	Pitch Rate	deg/sec
R	Yaw Rate	deg/sec
phi	Roll Attitude	deg
theta	Pitch Attitude	deg
psi_ang	Heading Angle	deg
del_th	Thrust Command	%
del_e	Pitch Command	%
del_r	Yaw Command	%
del_b	Ballonet Command	%

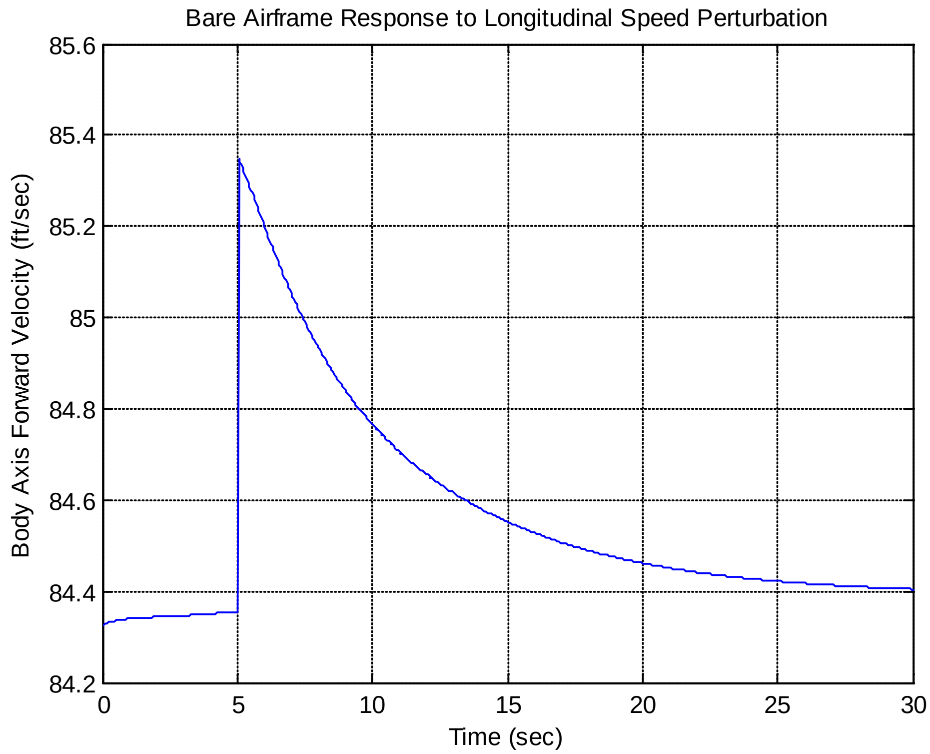


Figure A- 46. Bare Airframe Response to Longitudinal Speed Perturbation

A14 STRUCTURES DEFINITION

The structures definition page contains airship geometry coordinates that are used for a structural analysis of the airship hull. The material properties at each longitudinal station are displayed, as defined on the Performance sheet. After running a structural analysis from the Control Sheet, the maximum stresses calculated for each panel are output below the geometry definition on the Structures Definition sheet. The structural weight of the vehicle is calculated based on the minimum structural material required to meet the user-input stress limits.

A15 AERODYNAMIC LOADS

A15.1 Loads Concept

This page is based on additional data from the aforementioned series of CFD runs. The data reports the lift force along the length of the selected airship envelope according to its length to height ratio (L/H) and length to width ratio (L/W). This information is used elsewhere in the tool to estimate loads and moments on the envelope.

Two different general envelope forms are provided: tri-lobe and bi-convex. Eight variations in L/H and L/W are provided for each general form. Lift force distributions are provided for these 16 runs at two angles of attack, 3° and 30°, giving a total of 32 columns of data. Data for each tri-lobe and bi-convex form assumes an airspeed of 100 ft/sec, a dynamic pressure of 11.80 lb/ft^2 and a 300-ft length.

A15.2 Loads Inputs

There are no user inputs on this page.

A15.3 Loads Calculations

The calculations are divided into four quadrants defined by form (tri-lobe or bi-convex) and angle of attack (3° and 30°). Calculations in each quadrant are performed in the same way.

The basic lift force data from the CFD runs is arrayed in columns of 36 rows. Each column pertains to a single combination of L/H and L/W. This data is interpolated in two stages. Each stage is a two-dimensional interpolation. The first stage performs three columns of 2-D interpolation, one column for each of the three pre-selected L/W ratios (2.00, 2.54 and 3.08). Each column finds the lift force for its L/W ratio for the L/H ratio of the airship selected in the Performance page.

The second stage of interpolation interpolates the lift force for the L/W ratio of the airship selected in the Performance from the three columns of data in the first interpolation stage. This process produces 36 rows of lift data for the airship selected in the Performance page, according to its L/H and L/W. This final row of data is plotted in the upper right corner of each quadrant.

A16 LOADING

The Loading page pertains to the structural load imposed on the envelope by the combined forces of empty weight, payload, buoyancy and aerodynamic loads. The primary output from this page is the bending moment imposed on each longitudinal station for each aerodynamic load case. This is used to estimate the needed envelope structure and the weight thereof.

There are no user inputs on this page.

A17 CONTROL

The Control page is used to run structural sizing routines based on the Structures Definition, Aerodynamic Loads and Loading pages.

The Control page is operated by clicking the “Run LTA Strength” macro button. This runs a series of macros that estimates stresses and weights in the envelope structure.

A18 AERODYNAMICS

A18.1 Aerodynamics Concept

The Aerodynamics page calculates drag for conventional envelopes, fins, nacelles and gondolas. There are very few user inputs. Lift and drag characteristics for multi-lobe and bi-convex envelopes are determined on two other separate pages.

A18.2Aerodynamics Inputs

There are almost no user inputs on this page. See Section A18.3.3.

A18.3 Aerodynamics Outputs and Calculations

This page estimates total airship drag by calculating the drag of each component individually and summing the values. This drag value assumes that none of the components except the envelope make lift. Drag values are provided for five speeds likely to cover the airship's operating range.

The following components are considered:

- Up to eight individually sized fins
- Up to eight individually sized engine pylons
- Up to eight individually sized engine nacelles
- A single gondola
- Up to three additional miscellaneous components
- A single airship envelope

A18.3.1 Fin and Pylon Drag

For each of the five selected airspeeds, a drag estimate for each fin and pylon is made using the same process.

- An ideal skin friction coefficient is estimated according to the surface's Reynolds number. This based on the specified operating altitude, airspeed and surface mean aerodynamic chord.
- A skin roughness factor is assumed to be 1.06.
- A form factor for the surface is estimated from its thickness-to-chord ratio.
- The wetted area of the surface is estimated to be 2.047 times its projected area.
- The equivalent flat plate drag area of each surface is calculated as the product of the skin friction coefficient, skin roughness factor, surface form factor and surface wetted area.
- The effect of envelope boundary layer and prop wash on drag force is not considered.

A18.3.2 Nacelle

For each of the five selected airspeeds, a drag estimate for each nacelle is made.

- An ideal skin friction coefficient is estimated according to the nacelle's Reynolds number. This based on the specified operating altitude, airspeed and nacelle length.
- A skin roughness factor is assumed to be 1.06.

- A reference wetted area is estimated as the product of 0.68, Pi, nacelle length and nacelle width.
- A form factor of 1.32 is assumed.
- The equivalent flat plate drag area is calculated as the product of the skin friction coefficient, skin roughness factor, surface form factor and reference wetted area.
- The effect of envelope boundary layer and prop wash on drag force is not considered.

A18.3.3 Gondola and Miscellaneous Components

Equivalent flat plate drag area of the gondola and up to three miscellaneous components is simply estimated. It is assumed to be independent of airspeed.

- The frontal area for the gondola is automatically entered. Frontal area for the miscellaneous components is also automatically entered from the Layout page.
- The user enters a frontal drag coefficient for the gondola and each miscellaneous component.
- The equivalent flat plate drag area is the simple product of frontal area and frontal drag coefficient.

A18.3.4 Envelope

Equivalent flat plat drag area of the airship envelope is estimated using Hoerner's hull drag method. This is an empirical method based the size and proportions of the envelope.

In addition to the zero-lift flat plate drag area calculation described above, drag area as a function of envelope lift coefficient is also estimated. This estimate is based on a combination of CFD and wind tunnel test data for the U.S.S. Akron bare hull as shown at the right side of the page. The result is a table titled "Round Airship Hull Drag" that shows flat plate drag areas for lift coefficients from 0.0 to 0.5 for airspeeds from 5 ft/sec to 200 ft/sec. This data provides a basis for envelope drag when buoyancy is not neutral.

A19 BI-CONVEX CFD

A19.1 Bi-Convex CFD Concept

The Bi-Convex page is a database used by other pages to estimate lift and drag characteristics for bi-convex envelopes. A matrix of eight representative airship forms was evaluated using computational fluid dynamics (CFD) over a range of four angles of attack, using CFD++.

The bi-convex envelope form may of interest for two reasons. First, a symmetrical bi-convex cross section provides the greatest possible width for a given perimeter and volume. Width can be beneficial for lifting body airships. Second, the bi-convex cross section is formed of upper and lower circular arcs. This cross section can be created by a simply pressurized membrane envelope supported by a perimeter frame.

The eight airship forms are derived from three length to height (L/H) ratios (5.00, 7.07, and 10.61) and three length to width (L/W) ratios (2.50, 2.53, and 5.31). The ninth and most blunt form in this matrix is not pursued. Figure A- 47 illustrates the mid-matrix bi-convex form.

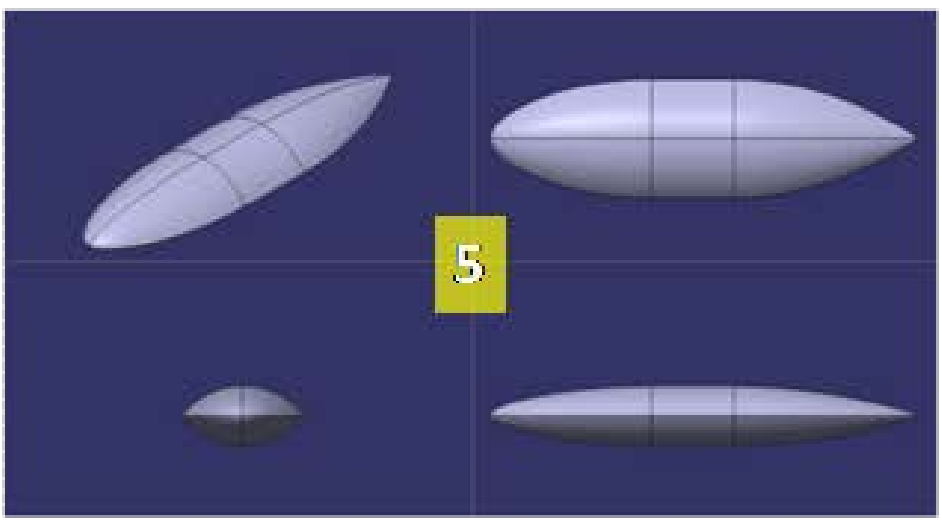


Figure A- 47. Example Bi-Convex Form with 7.07 L/H and 3.53 L/W.

A19.2 Bi-Convex Inputs

There are no user inputs on this page

A19.3 Bi-Convex Calculations

The page is based on data from a series of CFD runs. Eight angles of attack are run for each of the eight tri-lobe envelope forms. Forces and moments are recorded for the 64 different runs. Key results are lift coefficient (CL) and drag coefficient (CD).

L/H and L/W for the airship selected on the Performance page is entered on the page automatically. A two-dimensional interpolation of lift and drag results is run to provide tables of CL versus CD for the selected L/H and L/W at three different dynamic pressures and associated

Reynolds number. This table is used by the Performance page to assess aerodynamic performance only if the “Bi-Convex” envelope type is selected.

A20 TRI-LOBE CFD

A20.1 Tri-Lobe CFD Concept

The Tri-Lobe CFD page is a database used by other pages to estimate lift and drag characteristics for multi-lobe envelopes. A matrix of eight representative airship forms was evaluated using computational fluid dynamics (CFD) over a range of six lift coefficients, using CFD++.

The eight airship forms are derived from three length to height (L/H) ratios (3.38, 4.30, and 5.21) and three length to width (L/W) ratios (2.00, 2.54, and 3.08). The reader may note that three times three is greater than eight – the 3.38 x 3.08 form is not pursued due to its extreme combination of depth and width. Figure A- 48 illustrates the mid-matrix tri-lobe form.

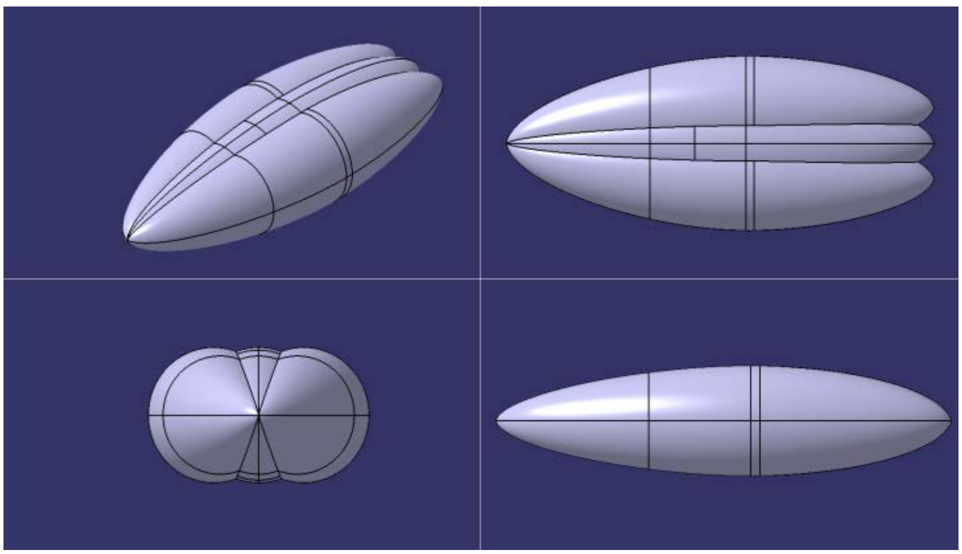


Figure A- 48. Example Tri-Lobe Form with 4.30 L/H and 2.54 L/W.

A20.2 Tri-Lobe CFD Inputs

There are no user inputs on this page

A20.3 Tri-Lobe CFD Calculations

The page is based on data from a series of CFD runs. Eight angles of attack are run for each of the eight tri-lobe envelope forms. Forces and moments are recorded for the 64 different runs. Key results are lift coefficient (CL) and drag coefficient (CD).

L/H and L/W for the airship selected on the Performance page is entered on the page automatically. A two-dimensional interpolation of lift and drag results is run to provide a table of CL versus CD for the selected L/H and L/W. This table is used by the Performance page to assess aerodynamic performance only if the “Tri-Lobe” envelope type is selected.

A21 MISSION

A21.1 Mission Concept

The Mission page permits the selected airship to be "exercised" on a selected origin-destination pair to determine its performance in the "real world". The mission page applies historical wind data from the Wind2 page and the airship's still-air performance from the Performance page.

The general idea is that the user may select an origin-destination pair, an altitude and a season. The tool then flies the airship along the great circle route between the origin and destination with winds typical for the selected season and altitude along that route. The tool neither optimizes the route to take advantage of tailwinds nor minimizes headwinds.

The selected route trajectory is shown on a large map of the globe along with wind vectors, if desired.

A21.2 Mission Inputs

Inputs on this page include pull-down menus, check boxes and manual data entry.

- Origin and Destination. These pull down menus enable the user to select an origin and destination from a pre-selected list.
- Custom Longitude and Latitude. By checking this box, the user may enter precise latitudes and longitudes of his choice while disabling the pull-down origin and destination selections. The inputs are in decimal degrees; negative latitudes are south of the equator and negative longitudes are west of the prime meridian.
- Date, Time and Time Zone. The date, time and time zone inputs are used on the "Solar" page to estimate the sun azimuth and elevation at the start of the mission. These are automatically updated on the Solar page for each mission waypoint so the sun angle changes along the route.
- Altitude. This manual input influences both the airship's native performance and the winds on-route.
- Season. This pull down menu allows the user to select from four seasons or a yearly average. This selection influences the winds on-route.
- Display Wind Vectors? This check box turns on wind vectors on the world map.

A22 WIND2

A22.1 Wind2 Concept

This page is a wind database for use by the Mission page.

The output portion of this page is structured in two large tables – one for wind direction and one for wind speed for a matrix of latitudes and longitudes. The cell values vary according to the specified altitude and season.

A22.2 Wind2 Inputs

There are no user inputs on this page – the needed latitude, longitude, altitude and season are determined on the Mission page.

A22.3 Wind2 Calculations

Values in the wind “direction” and “velocity” tables are based on data tables in the bottom portion of the spreadsheet. These data tables have wind direction and velocity for the five selectable seasons (spring equinox, summer solstice, fall equinox, winter solstice, and full-year average). The output values are based on a cascading “if statement” that selects the correct data table below.

A23 BUOYANCY COMPENSATION

A23.1 Buoyancy Compensation Concept

This page permits the user to pressurize a discrete internal vessel (aka "tank" on this page) as a means to adjust airship buoyancy. The vessel is assumed to be a cylindrical tank with hemispherical end caps. Side-by-side inputs may be made for two different tank materials. For example, one tank can be a conventional material such as nylon; the other can be a more exotic material such as Dyneema fiber with Mylar film as a seal. The vessel material is assumed to have the same strength in the hoop and longitudinal direction.

Outputs from this page include tank buoyancy effect, tank weight and energy needed to fill the tank to capacity.

A23.2 Buoyancy Compensation Inputs

Inputs are made in two categories. First, the dimensions and mechanical properties of the vessel are specified. Second, inputs relevant to pressurizing energy are made.

Dimensions and Mechanical Properties

- Vessel diameter and constant section length. These are the key vessel dimensions. Hemispherical end caps are assumed.
- Gauge pressure. This is the differential pressure between the vessel interior and its exterior.
- Fabric density. This is the density of the vessel material. This input is based on the nominal thickness of the material. The density excludes any film or coating added to inhibit leakage.
- Fabric ultimate stress. Fabric stress is based on the same nominal thickness of the cloth as used for the density input above. Again, the strength is assumed to be the same in the hoop and longitudinal directions.
- Safety factor. This is the ratio between fabric ultimate stress and the stress seen by the fabric in the hoop direction at the gauge pressure specified above.

Inflation Energy

- Atmosphere absolute pressure. This is the atmospheric pressure outside the vessel.
- Ambient Temperature (R). This is the absolute temperature of the gas outside the pressure vessel.
- Pump efficiency. This is the ideal mechanical energy of the compressed gas divided by the mechanical energy input to the pump
- Electric motor efficiency. This input applies to an electric motor powered compressor pump and includes the combined motor and motor-controller efficiency.
- Compression time. This is the length of time in which the vessel is to be compressed. It is the basis for the average power required output.

A23.3 Buoyancy Compensation Calculations and Outputs

Key outputs for this section are pressure vessel weight, the ratio of stored gas weight to vessel weight, compression energy and compression power.

The pressure vessel skin thickness is estimated based on hoop tension and skin strength. The skin weight is estimated from the vessel's surface area, the skin thickness and the skin density.

Reduced buoyancy is calculated according to the sea-level density of helium times the compression pressure of the tank divided by sea level pressure. Compressed helium mass is computed from the tank absolute pressure, its density at the specified ambient temperature, and the tank volume. A consideration with this is that the gas may be at an elevated temperature from its compression by the pump. At first the tank will be hotter and less dense and lighter. As it cools, the temperature will decline and more gas can be pumped to bring it back up to limit pressure.

Specific energy required to compress the gas into the tank is determined by gas constants, starting and ending pressure, ambient temperature, compressed gas mass, and pump and motor efficiency. Total energy required is the product of specific energy and the compressed gas mass. Average power required is the total energy divided by compression time.

A24 SOLAR

A24.1 Solar Concept

This page pertains to airships with photo-voltaic solar cells mounted to the envelope exterior. These cells may provide power for propulsion or for systems.

The user defines solar cell characteristics and the size of the entire solar array. The page then pulls data from the Mission page so that the sun azimuth and elevation angle can be determined at each mission waypoint. This is used to calculate incident solar irradiation and energy received over the course of the mission.

This iteration of the tool assumes a horizontal, planar solar array. That is, the tool does not yet account for the shape of the envelope and the variation in illumination received by different cells. The effect of airship heading and roll angle is also absent in this version.

A24.2 Solar Inputs

Inputs are made in three fields:

- Solar energy model parameters
- Solar panel parameters
- Array size

A24.2.1 Solar Energy Model Parameters

These inputs define atmospheric and cloud attenuation parameters. These inputs are influenced by airship altitude, location and season. In this version of the tool, these inputs rely on the designer's judgment rather than on a more complex model that automatically provides statistically valid inputs. However, default values are suggested.

- Ryan-Stolzenbach atmospheric transmission factor. This is the fraction of energy remaining in the sunlight reaching the airship in comparison with that in space. A range of 0.70 to 0.91 is suggested, with a default value of 0.80. Lower altitude and increased humidity lead to lower values.
- Coefficient for cloud correction. This value influences the calculated albedo (sunlight reflected from clouds). Although clouds may shade the airship from direct sunlight they also provide significant reflected light. A default value of 0.65 is suggested. Factors that influence this value include the extent to which the airship is flying above or alongside clouds and its solar cell arrangement. For instance, cells on the bottom of the airship are more responsive to albedo.
- Exponent for cloud adjustment. This is also used in the calculation of albedo. A default value of 2.0 is suggested.
- Cloud cover fraction. This input defines the fraction of sky covered by cloud. An input of zero indicates a cloudless sky; a value of one indicates overcast.

A24.2.2 Solar Panel Parameters

This section permits the user to select a solar cell type from a pull-down menu and to define the areal weights of associated components.

- Solar cell selection. A pull-down menu permits the user to select a solar cell type from a built-in list. Selection automatically enters cell efficiency and areal weight in nearby cells. A table of available cells is found to the right of this input block in Cells G25: L28.
- Cell packaging factor. This is the fraction of the total array area occupied by solar cells. A default value of 94% is suggested as a default value with an upper limit of 96% - higher values are impractical due in part to thermal expansion concerns.
- Cover film. This is the areal weight of the film used to cover the outer surface of the solar cell array, if any.
- Adhesive. This is the areal weight of the adhesive used to bond the solar cells to its substrate and the substrate to the airship.
- Substrate. This is the areal weight of a support material behind the solar cells that permits their handling, wiring and connection the airship envelope.
- Harnessing. This is the areal weight of the wiring harness that connects the solar cells to

A24.2.3 Array Size

The data block labeled "Solar Array" includes a single input along with a summary of array areas and weights.

- Array % of envelope wetted area. This input defines the total solar array surface area as a fraction of the total envelope wetted area. The logical range for this input is zero to one, but it is possible to cover fins, nacelles, pylons and the gondola with cells as well, so the maximum value could exceed one in an extreme design.

A24.3 Solar Outputs

Outputs from this page are of two types: array weight and array energy provided.

Components of array weight are summarized in the data block labeled "Solar Array."

Array energy provided is shown in the right-most column on the spreadsheet with the heading "Cumulative solar energy (Whr/m^2)". This column is a running total of the total energy provided to the airship during the course of the mission. This is shown in terms of Watt-hours per square meter of solar panel.

A25 INTERNAL COMBUSTION ENGINE

A25.1 Internal Combustion Engine Concept

The IC Engine page pertains to the design and characteristics of reciprocating piston engines. The overall efficiency and sea-level power of the engine(s) are specified on the Performance sheet, and the IC Engine page is used for efficiency adjustments and power available calculations. No configuration specific user inputs are required on this sheet, although the curve representing the relative engine efficiency at different throttle settings can be adjusted if desired. An important function of this sheet is the calculation of engine power for a specified supercharger/turbocharger boost. The inputs for the boost are specified on the Performance sheet.

The user may use this page to estimate engine performance based on specific engine specifications. These include stroke length, displacement volume and fuel type. The resulting bSFC can then be manually entered into the Performance sheet.

A26 SURVIVABILITY

A26.1 Survivability Concept

The purpose of this page is to provide a preliminary survivability estimate for a specific airship based on its cruise altitude, threat countermeasures, geometry and systems characteristics. This estimate is provided for different classes of threats.

Two related pages augment the Survivability page. Additional detail regarding threats is provided in the "Threat Detail" page. The "Countermeasures Detail" page provides details on countermeasures including average system weights for signature management and vulnerability reduction. This page also enables the user to select the type and number of each countermeasure system to obtain a total countermeasures system weights – this input is automatically entered on the Survivability page.

The Survivability page is organized as a matrix with different threat classes running across the top row. Vehicle characteristics categories are listed in the first column. Inputs and outputs are located in the body of the matrix according to the threat and characteristic.

The first column is organized into three sections. The first section estimates the susceptibility of the airship; this is the probability that the airship will be hit by a threat (Ph). The second section estimates vulnerability; this is the probability that the airship will be killed given a hit (Pkh). The final section combines Ph and Pkh to estimate the probability of survival per encounter.

Many of the inputs are provided by the user; others pertaining to the airship characteristics are drawn from other pages in the tool. Figure A- 49 shows the threat classes included in the matrix.

1	2	3	4	5	6	8	7
Small Arms & Ballistic (7.62mm - 14.5mm)	Anti-aircraft cannon (23mm - 30mm)	Short Wave IR SAM (MANPADS)	Long Wave IR SAM (MANPADS)	Short Range RF SAM	Long Range RF SAM	Directed Energy	Air To Air

Figure A- 49. Survivability Matrix Threat Classes

A26.2 Survivability Inputs

User inputs are made in the yellow cells. Some inputs are made for each individual threat class; others, such as geometric characteristics, are common for all threat classes.

A26.2.1 Probability of Hit

- Altitude Above Ground Level (AGL). This input supports an automatic input for the "Mission Altitude Zone" row for each threat class. Note that there is a comment in each cell that describes the effect of altitude on the cell's value.
- Threat Countermeasures. User estimates of threat countermeasure effectiveness are entered in each column. The range of inputs values is 0.0 to 1.0. A value of 1.0 means that there is no effective countermeasure; highly effective countermeasures rate a value of 0.1 or less. Guidance for these judgments is provided in the input cells' comments. The following page, "Threat Detail", provides additional guidance on each threat type.
- Signature Management. This input is the user's estimate of ease of detection for each threat type, considering the airships altitude above ground level. The range of inputs

values is 0.0 to 1.0. A value of 1.0 indicates an easily detected vehicle; a very difficult-to-detect vehicle has a value of 0.1 or less. This value can be thought of as the likelihood of being detected. Figure A- 50 shows inputs for a 500 foot altitude example and the pop-up menu for altitude related inputs.

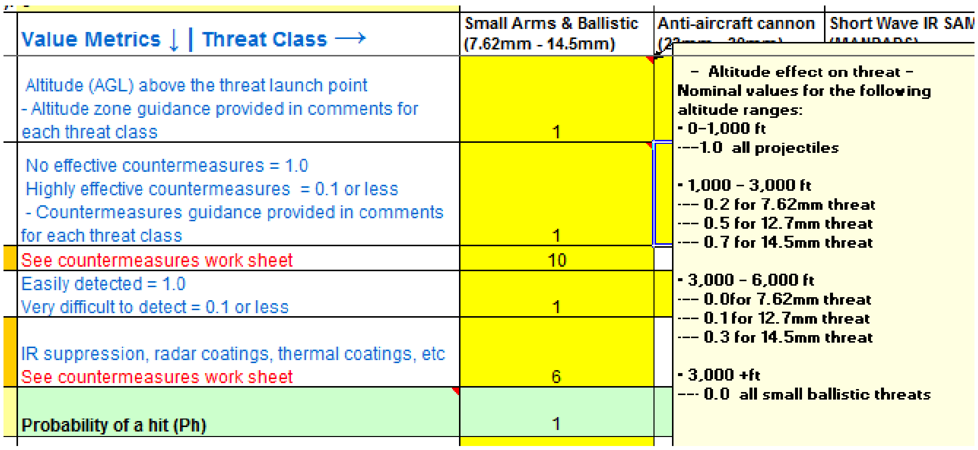


Figure A- 50. Survivability Probability of a Hit Example

A26.2.2 Probability of a Kill

- LTA Lift Gas, Structure & Envelope Robustness. The range of inputs values is 0.0 to 1.0. For this input, a low value indicates the airship is resistant to the threat; a high value indicates vulnerability. Each input cell has a comment pertaining to the input. Airships with hydrogen or other flammable lifting gas should have an input of 0.8 or greater.
- LTA Propulsion & Energy Systems Robustness. These inputs describe the resistance of the propulsion and energy systems to a hit from each threat type. The range of inputs values is 0.0 to 1.0. Very resistant or redundant systems rate 0.1 or less; Low resistance or low redundancy systems rate 0.9 or greater. “Energy systems” refers to, for example: fuel tanks, fuel lines, solar cells, batteries, propulsion wiring and so on.
- LTA Command and Control Robustness. These inputs describe the resistance and redundancy of the flight control system (in all its permutations) to a hit from each threat type. The flight control system may include the flight control computer, avionics, signal receivers and transmitters, connection to flight control actuators, flight control actuators and aerodynamic control effectors. The range of inputs values is 0.0 to 1.0. A system highly resistant to a given threat rates a value of 0.3 or less. A system that is not effective against a threat rates 1.0.
- LTA Vulnerability Reduction Systems. A vulnerability reduction system mitigates or limits damage to lift gas, structure and envelope; propulsion and energy systems; and command and control system after damage has been done. A fire protection system is an example vulnerability reduction system. In this tool, it is assumed that the vulnerability reduction system *__is__* a fire protection system and that its effect, if employed, is to improve the robustness of the propulsion and energy system. A system that is highly effective against a specific threat is rated 0.3 or less; an ineffective system is rated 1.0.

A26.3 Survivability Calculations and Outputs

There are three primary products of this page: susceptibility (Ph), vulnerability (Pkh) and survivability. The calculation of each (for each threat type) is described.

- Susceptibility (Ph) is the product of Mission Altitude Zone, Threat Countermeasures and Signature Management as described in Section A26.2.1. The range of values for susceptibility is 0.0 to 1.0 where 0.0 is insusceptible (can't be hit) to 1.0 (will be hit every time).
- Vulnerability (Pkh) is an area-weighted average of 1) Lift Gas, Structure & Envelope Robustness, 2) Propulsion & Energy Systems Robustness, and 3) Command and Control Robustness. These terms are described in Section A26.2.2.
- Each of these three terms is multiplied by its projected area.
- The Propulsion & Energy Systems Robustness term is additionally multiplied by the Vulnerability Reduction Systems input. This accounts for the beneficial effect of what is assumed to be a fire protection system on the vulnerability of the Propulsion & Energy Systems.
- The sum of the three terms is divided by the sum of the three projected areas.
- Total Encounter Survivability Result. This is one minus the product of Ph and Pkh. High values for Ph and Pkh give a low probability of survival per encounter.

A secondary output of the Survivability page is the weight of the Signature Management systems and the Vulnerability Reduction Systems as well as the combined, total weight of these. These weights are estimated on the Countermeasures Detail page and are automatically entered on this page. The two systems weights are simply added to find a total. Figure A- 51 shows probability of kills and survival results for an LTA at 500 foot altitude against small arms and cannon fire. Probability of survival is reduced for cannon fire, due to increased lethality of cannon

Lighter Than Air Vehicle Survivability Matrix

AGL (ft):	0	1	2
	Value Metrics ↓ | Threat Class ⟶	Small Arms & Ballistic (7.62mm - 14.5mm)	Anti-aircraft cannon (23mm - 30mm)
LTA Lift Gas, Structure & Envelope Robustness (Pk)	Highly redundant against that threat = 0.05 or less Not redundant against that threat = .8 or greater Note: if the lift gas is hydrogen (or other flammable gas) this value should be 0.8 or greater.	0.05	0.15
LTA Propulsion & Energy systems Major cross-section area (ft^2)	This is the cross-section area of the critical propulsion and energy systems as seen from the likely threat approach direction. (ft^2)	95	95
LTA Propulsion & Energy systems Robustness (Pk)	Highly redundant against that threat = .1 or less Not redundant against that threat = .9 or greater	0.2	0.2
LTA Command and Control Major cross-section area (ft^2)	This is the cross-section area of the critical command and control systems as seen from the likely threat approach direction. (ft^2)	50	50
LTA Command and Control Robustness (Pk)	Highly redundant against that threat = .1 or less Not redundant against that threat = .9 or greater	0.1	0.2
LTA Vulnerability Reduction Systems (These are typically fire protection systems.)	Not effective against that threat = 1.0 Highly effective against that threat = .3 or less Note: A value of less than 1 will act to improve the robustness of the propulsion and energy systems	0.25	0.25
Vulnerability Reduction Systems Weight (lbs)	Weight of fire protection systems, etc.	20	
Vulnerability Result: Gas/Size/Robustness /Vuln-reduction	Probability of a Kill Given a Hit (Pkh)	0.052	0.144
Total Encounter Survivability Result: (Probability of Survival for 2 hour+)	= 1 -Ph x Pkh (A value of 1 = a high probability of survival for2+ hours)	94.78%	85.61%
Total Survivability Driven Weight (lbs)	Countermeasures/Signature/Vulnerability	36	

Figure A- 51. Probability of Kill and Survival Output for Small Arms and Cannon Fire.

A27 THREAT DETAIL

A27.1 Threat Detail Concept

This page supports the Survivability page (Section A26) with a description of weapons in the different threat categories. Damage effects of each threat are described, with emphasis on effects on lighter than air vehicles.

A27.2 Threat Detail Inputs

There are no user inputs on this page.

A27.3 Threat Detail Calculations and Outputs

There are no calculations on this page.

A28 COUNTERMEASURES DETAIL

A28.1 Countermeasures Concept

This page supports the Survivability page (Section A26) with a description of countermeasures. This page is divided into four different categories:

- Countermeasures and threat warning
- Threat intercept and defeat defense
- Radar signature coatings
- Fire protection systems

In addition to descriptions of the different types of systems in these categories, a typical weight is provided for each system. The user may enter the number of systems of each type. The page calculates their weight and automatically enters the weight on the Survivability page.

A28.2 Countermeasures Inputs

The user may enter "quantity used" for each of the different systems. Guidance for the best quantity to enter is provided in the notes in the right hand column.

A28.3 Countermeasures Calculations and Outputs

Calculation of system weight is straightforward. Quantity is multiplied by average system weight. The results are summed to give a total for Countermeasures and Threat Warning, Threat Intercept and Defeat Defense, Radar Signature Coatings and Fire Protection System.

LIST OF ACROMYMS, ABBREVIATIONS, AND SYMBOLS

ACRONYM	DESCRIPTION
A3D	Advanced Airship Analysis and Design
ACLS	Air Cushioned Landing System
AFRL	Air Force Research Lab
CFD	Computational Fluid Dynamics
HALE	High Altitude Long Endurance
ISR	Intelligence, Surveillance, Reconnaissance
L/D	Length-to-Diameter
MHB	Maximum Half-Breadth
SFC	Specific Fuel Consumption
VRML	Virtual Reality Markup Language